Energy, Mines and Resources Canada

Énergie, Mines et Ressources Canada

CANMET

Canada Centre for Mineral and Energy Technology

Centre canadien de la technologie des minéraux et de l'énergie

Mineral Sciences Laboratories

Laboratoires des sciences minérales

MINERAL SCIENCES LABORATORIES

ANNUAL REPORT 1989/90

Canada

MINERAL SCIENCES LABORATORIES

ANNUAL REPORT 1989/90

CANADA CENTRE FOR MINERAL AND ENERGY TECHNOLOGY

ENERGY, MINES AND RESOURCES CANADA

DIVISION REPORT MSL 90-69 (TR)

93-00135/

FOREWORD

The Mineral Sciences Laboratories prepares two annual reports. This report is essentially a summary of the research and related activities carried out in the laboratories. It is in effect an historical record of the fiscal year 1989/90. A second report is oriented toward the external reader. It provides an overview of the laboratories' research with aspects selected from the longer report. It is intended to be a means of communication to industry and the public.

This annual report reflects the breadth and scope of research in the laboratories. The considerable volume of work performed under contract to specific clients is not recorded in detail, since such detail is the privy of our clients.

The preparation of the Annual Report has been coordinated by Linda Wilson, a Physical Scientist in the Pyrometallurgy Section. Her hard work has been central to this report. Inputs from the entire staff of the laboratories provided the comprehensive documentation. Special thanks to Susan Lord for her editorial efforts.

Comments should be directed to:

Dr. I.J. Itzkovitch
Director
Mineral Sciences Laboratories

AVANT-PROPOS

Les Laboratoires des sciences minérales préparent deux rapports annuels. Ce rapport est essentiellement un résumé des recherches et des activités connexes des laboratoires. C'est effectivement un dossier historique de l'année financière 1989/1990. Un autre rapport est destiné aux lecteurs de l'extérieur. Il contient un aperçu des recherches des laboratoires selon des aspects sélectionnés du plus grand rapport. Il a été conçu pour être un moyen de communication avec l'industrie et le grand public.

Ce rapport annuel reflète l'ampleur et l'étendue de la recherche dans les laboratoires. Le volume considérable des travaux réalisés sous contrat pour des clients spécifiques ne sont pas rapportés en détail, puisque certains de ces détails sont la propriété privée de nos clients.

La préparation du Rapport annuel a été coordonnée par Linda Wilson, scientiste à la section de Pyrométallurgie. Son travail dévoué fut essentiel à la réalisation de ce rapport. Des renseignements provenant de tout le personnel des laboratoires sont à la source de cette vaste documentation. Un merci spécial à Susan Lord pour son travail d'éditorial.

Vos commentaires peuvent être acheminés à:

Dr. I. J. Itzkovitch
Directeur
Laboratoires des sciences minérales

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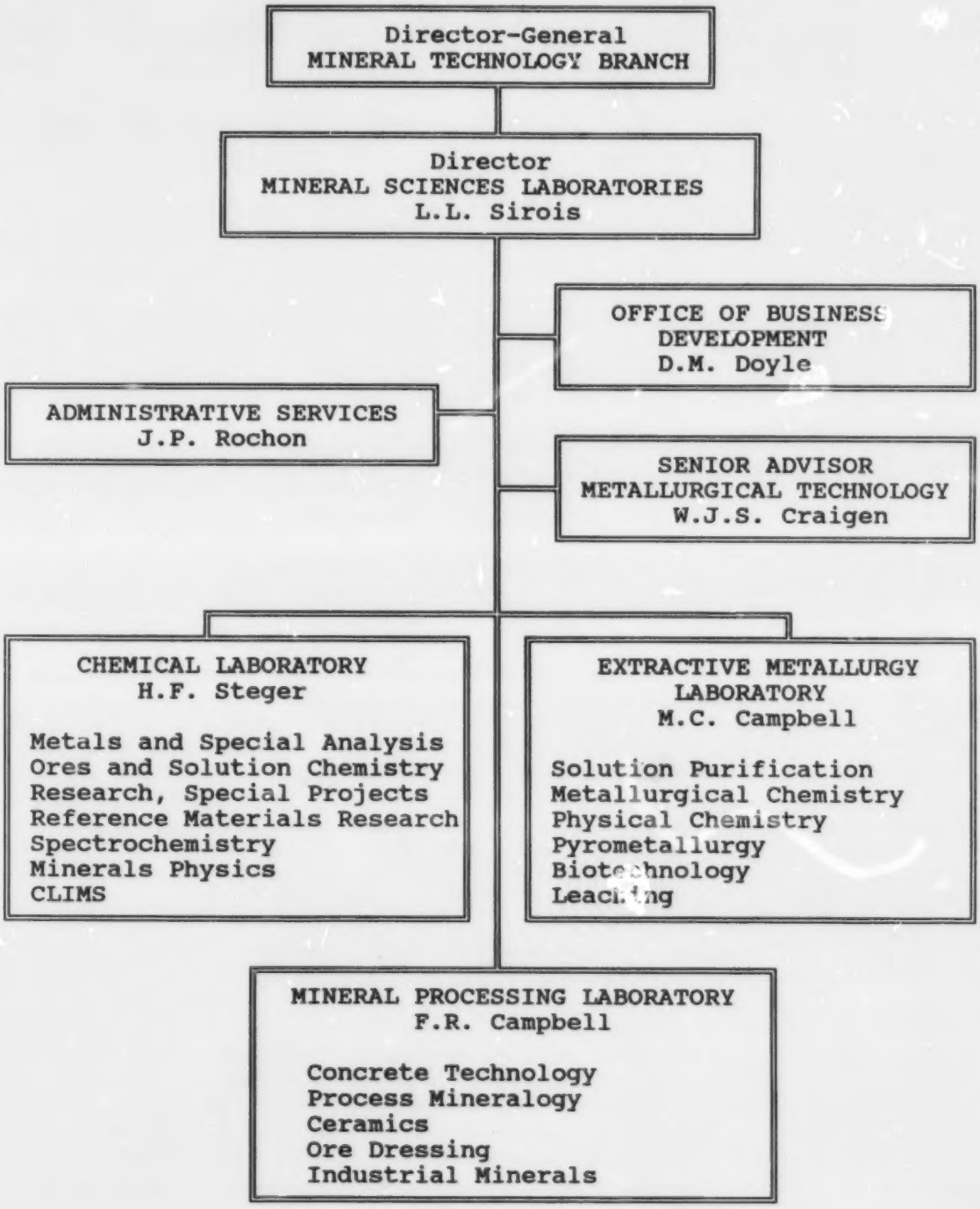
ORGANIZATION

CANADA CENTRE FOR MINERAL AND ENERGY TECHNOLOGY (CANMET)



DISTRIBUTION OF RESOURCES

MSL - FISCAL YEAR 1989-90

PROGRAM - MINERAL AND EARTH SCIENCES
ACTIVITY - "A-BASE"

SUB-ACTIVITY	MSL $000's
20. COAL MINING AND PREPARATION	
- Personnel (PY)	46(1)
- Operating	Nil
- Capital	Nil
30. MINERAL PROCESSING	
- Personnel (PY)	7890(171)
- Operating	1458
- Capital	1297
50. FUELS TECHNOLOGY	
- Personnel (PY)	46(1)
- Operating	20
- Capital	Nil
70. METALS AND MATERIALS	
- Personnel (PY)	92(2)
- Operating	5
- Capital	Nil
ACTIVITY TOTAL	
- Personnel (PY)	8074(175)
- Operating	1483
- Capital	1297

PROGRAM - MINERAL AND EARTH SCIENCES
ACTIVITY - ENERGY R&D

SUB-ACTIVITY	MSL $000's
20. COAL MINING AND PREPARATION	
- Personnel (PY)	Nil
- Operating	25
- Capital	Nil
30. MINERAL PROCESSING	
- Personnel (PY)	238(5)
- Operating	506
- Capital	529
50. FUELS TECHNOLOGY	
- Personnel (PY)	48(1)
- Operating	Nil
- Capital	Nil
70. METALS AND MATERIALS	
- Personnel (PY)	Nil
- Operating	Nil
- Capital	Nil
ACTIVITY TOTAL	
- Personnel (PY)	286(6)
- Operating	531
- Capital	529

PROGRAM - MINERAL DEVELOPMENT AGREEMENT
ACTIVITY - "A-BASE"

SUB-ACTIVITY	MSL $000's
30. MINERAL PROCESSING	
- Personnel (PY)	50(1)
- Operating	34
- Capital	Nil

PROGRAM - BIOTECHNOLOGY

ACTIVITY - "A-BASE"

SUB-ACTIVITY	MSL $000's
30. MINERAL PROCESSING	
- Personnel (PY)	Nil
- Operating	25
- Capital	Nil

HIGHLIGHTS

CHEMICAL LABORATORY

The Chemical Laboratory provided analytical support and carried out associated analytical method development for CANMET projects, other federal organizations and universities; provided umpire analysis service for uranium concentrates for the Blind River refinery of CAMECO; certified reference materials; and participated in committee work for standardization bodies. The Laboratory performed research in and provided support to CANMET projects and outside organizations in Mössbauer spectrometry, magnetic susceptibility and mathematical modelling.

The Chemical Laboratory maintained the chemical storesroom for MSL and other Divisions, provided a desktop publishing facility, acted as supervisor of the MSL management information system, supervised the continued development of the computerized MSL project information management system and provided support to MSL in health and safety issues such as WHMIS. An EMR Outstanding Merit Award for Occupational Health and Safety was received by Chemical Laboratory personnel in 1989.

During this review period, the Laboratory carried out 26,695 determinations of a wide variety of elements in 10,374 samples. Approximately 9% of these analyses were in support of revenue generating projects.

Through the Capital Acquisition and Replacement Plan, the Laboratory acquired an inductively coupled plasma-mass spectrometer and a Zeeman graphite furnace-atomic absorption spectrometer. These two techniques greatly extend the laboratory's capability in terms of selectivity and sensitivity of analysis.

Analytical research in this review period was directed towards, inter alia, the continued development of methods by atomic absorption techniques for determining trace levels of cobalt, nickel, lead, bismuth, indium and tellurium in raw and mineral processing materials, and a method by high performance liquid chromatography for separating and determining the oxidation products of thiourea occurring in gold leachates.

The Laboratory participated in collaborative analytical programs for major and minor elements for the analytical investigations undertaken by the Copper Refining Group and the Canadian Zinc Producers. In studies undertaken specifically for the Copper Refining Group, the sources of error in the determination of nickel in copper anodes and anode slimes were identified and a method was developed for determining tellurium in copper anode slimes having high selenium and silver.

Work for national and international committees continued. In particular, effort was directed towards collaborative laboratory testing and evaluation of analytical methods for the International Organization for Standardization. Examples are TC 102 for iron ore standards; TC 183 for standard methods of chemical analysis of copper, lead and zinc ores and concentrates; and REMCO, the

Council Committee on Reference Materials. Laboratory staff also served as technical committee chairpersons.

The Canadian Certified Reference Materials Project (CCRMP) provided analytical laboratories with reference materials for use in quality control and method development. Revenue from the sale of CCRMP materials was $157K. The number of units sold to Canadian clients grew by 13% whereas foreign demand declined by 30% compared with 1988. The sales of gold reference materials continued to predominate.

In 1989, a cooperative project with the Geological Survey of Canada led to the preparation of five geochemical reference materials for platinum group elements in diabase, peridotite and gabbro rock matrices. The gold (50 ppb), platinum and palladium values of another material, UMT-1, were established by an interlaboratory analysis program.

Mineral Physics again contributed to research projects in other MSL laboratories and the Metals Technology Laboratories. In particular, theoretical calculations on the effect of the operational parameters of a CANMET-developed rotating eddy-current magnetic separator provided a better understanding of its operation and recommendations for increasing its effectiveness. The Section's contribution to the MEND Program was a building-up of expertise with RATAP, a mathematical model for the estimation of the generation of acid in base metal tailings.

MSL was one of two Energy, Mines and Resources laboratories studied by the Lortie Commission Peer Review. This provided the Chemical Laboratory with the opportunity to demonstrate clearly its relevance, quality and effectiveness for the client in the Analytical Standards and Methods program area.

EXTRACTIVE METALLURGY LABORATORY

The Extractive Metallurgy Laboratory serves the Federal Government, the mineral industry and the Canadian economy through a comprehensive program of technological development and process enhancement. The group has specific expertise in applied chemistry, process metallurgy, biotechnology and environmental control technologies. The cadre of experienced professional and technical support staff is dedicated to addressing a wide range of technological challenges for a diverse clientele in the Canadian mineral industry.

The strong knowledge base of the laboratory is the key component of the range of services to industry. The strengthening of this knowledge base is critical in maintaining the service capability. Ongoing work in solution chemistry, formation and speciation of inorganic compounds, electrochemistry and thermochemistry renews the scientific strength of the laboratory. Applications in the enhancement of existing processes and in the development of new systems for metal recovery from Canadian ores demonstrate the value of the knowledge base. Close liaison with industry through contracts, joint research, cost-shared research and direct service insures relevance and ready transfer of technology.

Significant developments in the Extractive Metallurgy Laboratory in the past year include:

- support of Canada's non-ferrous smelting industry through monitoring of federally funded projects in flash converting, pyrrhotite rejection, increased roast, slag cleaning, smelter modernization, process improvement and waste treatment;

- sensor development for lead in slags and provision of an SO_2/SO_3 probe for off-gas streams;

- collaboration with the Canadian steel and coal industries in assessing future ironmaking technologies;

- sponsorship of work on the application of plasma technology to silicon carbide and titanium silicides;

- characterization of copper anodes and anode slimes to clarify the role and deportment of various impurities;

- analytical determination of nickel in copper anodes and slimes;

- determination of parameters for the conversion of jarosites to hematite for control of iron and impurities in zinc plants;

- elaboration of the effects of organic and inorganic species in zinc electrowinning;

- precipitation of platinum group metals with sodium borohydride;

- separation of PGMs using ion exchange;

- integration of ion exchange recovery of gold with acidification for cyanide recycle;

- application of microwave energy to carbon regeneration from gold mills;

- elaboration of the semiconducting behaviour of sulphide minerals;

- imposition of an emf on sulphide tailings to prevent acid mine drainage;

- assessment of various biomass to absorb uranium and the development of an economic process;

- biological treatment of industrial effluents including organics in recycle streams, destruction of recycle fluids, recovery of elemental selenium and mitigation of acid mine drainage;

- support of research on microbial plugging of porous zones in oil reservoirs;

- coordination of the efforts of the Mine Environment Neutral Drainage (MEND)-program with federal, industrial and provincial collaboration;

- sponsorship of the evaluation of acid mine drainage prediction techniques;

- establishment of a thermochemical data-base for nickel arsenides, ferric arsenate and lead arsenate;

- development of a thermogravimetric method for characterizing limestone utilization in fluidized bed combustion;

- determination that the presence of halides in fluidized bed combustion increases CO_2 and NOx emissions boding badly for the combustion of halogen-bearing organics as a disposal technique.

EML has also made a determined and persistent effort to increase the industrial support of laboratory work. Some 37 proposals have been made to Canadian companies and organizations to perform research work. EML has performed cost recovery work for 20 organizations with revenues totalling nearly $300K. In addition, EML has expanded its interaction with industry through working groups with industry on copper refining, zinc processing, gold metallurgy, ironmaking, biotechnology and tailings research. These working groups enable critical review of the ongoing research and research plans. Participants in these working groups find them valuable for the mutual exchange of ideas and for the insights into developing technologies.

MINERAL PROCESSING LABORATORY

The Mineral Processing Laboratory carried out in-house investigations, joint projects and contract studies in support of the needs of the Canadian minerals industry. The program is developed in close consultation with industry and with the provinces (especially through Mineral Development Agreements) and is carried out in cooperation with industrial R&D performers, private research companies, provincial research organizations and universities. Major projects are underway in the processing of metallic ores and industrial minerals, in the development and testing of improved concretes, and in the preparation and characterization of ceramic materials and products. These activities are supported by a range of mineralogical investigations, particularly aimed at process design and optimization.

An evaluation of the lead grinding circuit for Faro ore in the Yukon suggested that changes in grinding circuit design be considered. Much of the fine-grained liberated galena is currently reground to produce slimes, whereas a considerable proportion of unliberated galena is not reground.

An evaluation of iron ores from three mines in the Labrador trough showed that iron recoveries are higher for some mines than others because the ores are coarser grained. A special concentrating unit should be installed to recover the fine grained iron from the tailings.

The modes of occurrence and distributions of invisible gold in pyrite and arsenopyrite from many deposits were determined in collaboration with Surface Science Western, University of Western Ontario, by SIMS, cyanidation tests and mineral balances. The results provided new insights on the occurrence of invisible gold and are invaluable for designing new flow sheets and for redesigning existing ones.

Environmental studies carried out in collaboration with researchers from the Water Resources Centre at Waterloo, Ontario led to significant progress in understanding reactions between solids, pore water and oxygen in tailings, and in developing a potential practical method for neutralizing acid drainage.

CAMP software for numerical applications such as material balance and simulation reached a stage of completion that allowed its successful marketing on a worldwide basis. Some 55 software licences were issued in 12 different countries, for a value of over $100K. A third application of expert systems in industrial prototypes was realized at Kidd Creek Mines, a division of Falconbridge Ltd. in October 1989. The system performs validation tests on chemical compositions obtained from the on-line X-ray analyzer in the Cu and Zn flotation circuits. Whenever possible, invalid assays are replaced by reliable estimates. The project ended in October with a two day workshop presented jointly by the Kidd Creek Division and CANMET in Timmins.

CANMET Ceramics Consulting (C-Cubed) was launched in October 1989 in recognition of the needs and realities of the Canadian ceramics industry which is characterized by having many relatively small (50 employees), cash-poor companies which find it difficult to enter into major development programs even on a cost-shared basis. Consulting facilities and services are provided to industry in such a manner as to provide maximum flexibility to the members. Member companies purchase "time credits" with CANMET which they redeem over the course of a year as they see fit. Members can switch from a literature survey, to failure analysis, to statistical design all within a single initial time credit of 50 hours without the need for establishing contractual obligations initially or the need for major paperwork should they wish to redirect the work. By March 1990, eight members had joined C-cubed with interests covering the spectrum of the ceramics field including refractories, structural and functional materials.

The exploitation of statistical design has been pursued slowly with industrial clients because, for many, there is considerable confusion with statistical process control. However, increasingly, the more forward-looking companies have embraced the concepts and for the past two years have been increasingly involved with SD techniques - more recently as part of the C-Cubed program. As a consequence, over 12 companies are exploiting this methodology and requests for assistance from CANMET have increased. The first short course for industry will be held in early May 1990.

The production of sintered SiC bodies for use as a wear resistant and high temperature structural material benefited from statistical design methodology. In this case, the effectiveness (synergism and antergism) of a series of sintering aids was determined and demonstrated. By late 1989, the first of a series of sintered SiC bodies was produced having over 99% of theoretical density without resorting to pressure-assisted sintering (hot-pressing or hot-forging).

Transport Canada applied the CANMET developed technology of polypropylene fibre-reinforced high-volume fly ash concrete to cover acidic rock outcrops at the Halifax International Airport on a trial basis. Six test sections, each 100 x 50 ft in size, were placed to cover pyritic rock outcrops, including control panels. These panels will be monitored over the next 12 months to determine their performance. Initial results are promising.

A cost-shared research project was initiated with Hydro Quebec, Montreal and St. Lawrence Cement Company, Montreal to determine the feasibility of using high-volume fly ash concrete for dam concrete. To this effect, four large concrete monoliths (each 2.5 x 4.0 x 5.0 metres) were cast at a Hydro-Quebec facility at Laval, Quebec using field construction equipment. These monoliths are highly instrumented, and will be monitored over the next several years.

CANMET sponsored the 3rd International Conference on Fly Ash, Slag, Silica Fume and Natural Pozzolans in Concrete in Trondheim in June 1989, and the 3rd International Conference on Superplasticizers in Ottawa in October 1989.

Working closely with the iron ore industry, technology was developed in down-hole-analyses, enhanced dewatering of concentrates and improvements in iron concentrate recovery. CANMET was instrumental in forming a CANMET-industry consortium to improve iron ore beneficiation through process control.

Work was done for a variety of clients on the beneficiation of industrial minerals. New in 1989/90 was a strong interest in the recycle, separation and handling of industrial wastes, and work was also done for several industrial clients. The production of Summary Reports on past and current activities in selected commodities continued.

A CANMET industry program on column flotation was initiated during the year, the initial phase consisting of sparger and equipment evaluation. Bench scale research and development concentrated on improvements in tin flotation and copper zinc separation.

MINERAL DEVELOPMENT AGREEMENTS

Phase I Mineral Development Sub-Agreements (MDA-1's) which commenced in 1984/85 under the renewed Economic and Regional Development Agreements were signed with both Territories and all provinces except Alberta. CANMET is directly responsible for delivery of the federal portion of the Research and Technology Sectors of sub-agreements with Newfoundland, Nova Scotia, New Brunswick, Ontario, Manitoba and Saskatchewan. For sub-agreements with the Territories, CANMET has direct technical input; however, management responsibility rests with the Department of Indian and Northern Affairs (North of 60°). CANMET involvement with the British Columbia agreement is on a consultative basis only.

Initially there was no involvement for CANMET for the Quebec MDA; however a new program within the Agreement has been initiated entitled "Technological Assistance to Industry and Research Agencies in the Mineral Sector". This program involves CANMET on the federal side, Centre de Recherche Minerals on the provincial side and industry in cooperative projects.

As of March 31, 1990 the Sub-Agreements with five provinces, namely Newfoundland, Nova Scotia, New Brunswick, Manitoba and Saskatchewan came to a successful conclusion of the 6th or final "wrap-up" year. Discussions and in some cases negotations have been inplemented for renewal of these agreements.

Under the Agreements, Mineral Sciences Laboratories' role is, in consultation with the provinces and industry, to develop processing technology programs, provide expert advice and guidance and act as scientific authorities on contracts. Eighty separate contracts involving processing technology have been initiated to date. Total expenditures for 1989/90 on processing projects has been over $1.7M.

A brief review of each of the Agreements as they relate to Mineral Sciences Laboratories is given elsewhere.

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SPECIAL AWARDS

D.M. Doyle was named a Distinguished Lecturer by the Canadian Mineral Processors Division of the Canadian Institute of Mining and Metallurgy (CIM).

J.E. Dutrizac and T.T. Chen were co-recipients of the 1989 Metallurgical Society of CIM Best Paper Award for a three-part paper on the "Mineralogical Characterization of Anode Slimes from Inco's Copper Cliff Copper Refinery".

J.E. Dutrizac was the 1989 recipient of the Metallurgical Society's Silver Medal for "leadership in developing and sustaining the Metallurgical Society".

E.G. Joe received a CIM Fellowship Award for 1989.

CIM's New Brunswick Branch presented its 1989 Dr. W.J. Wright Award to W. Petruk for his contribution to the minerals industry in the province.

The American Concrete Institute has awarded A. Bilodeau, G.D. Brearley, G.G. Carette, R. Chevrier, E. Douglas, V.M. Malhotra, K.E. Painter, V. Sivasundaram, J.A. Soles and M. Venturino of the Concerete Technology Section the 1989 Charles S. Whitney Award "for their long-term contribution to research of specialty materials, such as fly ash and microsilica, to enhance the use of concrete as a construction material".

G.G. Carette was honoured for his contributions to the success of international conferences on concrete technology sponsored by CANMET and the American Concrete Institute.

The Combustion and Carbonization Research Laboratory of ERL along with a research scientist from MSL, C.A. Hamer, received a Public Service Merit Award for their contributions to the Industrial Fluidized Bed Demonstration Program at Canadian Forces Base Summerside, Prince Edward Island.

J.W. Wittwer received the Departmental Outstanding Merit Award for Occupational Health and Safety.

J.W. Wittwer and R.J. Guillas received a Public Service Suggestion Award for the design and adoption of a hazard awareness centre.

PART A. RESEARCH AND DEVELOPMENT

MINERAL AND ENERGY TECHNOLOGY ACTIVITY

COAL MINING AND PREPARATION SUB-ACTIVITY

Coal Desulphurization

Project 20.79.01: High Sulphur Coals
Project leader : K.S. Moon

Objective:

To contribute to the technology of economically upgrading high sulphur coals to meet more stringent specifications for thermal and metallurgical coals and future requirements for coal combustion, conversion and environmental regulations.

Atmospheric emission of SOx from coal-fed thermal power plants is a major source of acid rain in the Atlantic region of North America. Coal from Eastern Canada contains significant amounts of sulphur and thus contributes to the problem. The efficient removal of sulphur and ash containing minerals from high-sulphur coals prior to combustion would reduce this problem. Removal of unwanted components also increases the unit thermal value of coals and contributes to decreased transportation costs. Coal preparation will generally be necessary for coals destined for other uses such as liquefaction or gasification.

Highlights and Achievements:

a) Development of CANMET sulphur-form analyzer

A prototype CANMET sulphur-form analyzer was developed based on two patents granted for a quantitative analysis of different sulphur forms, such as organic, pyritic and sulphate sulphur, in coal. The procedure utilizes the SOx evolution kinetics for different sulphur forms in coal. The sulphur-containing coal sample is heated in the presence of air for the evolution of SOx gas. An infrared detector senses the concentration of SOx gas as a function of time. The chronogram thus obtained has multiple peaks characteristic to the concentration of different sulphur forms in the samples. A microprocessor converts the area under the peaks to the concentration of different sulphur forms utilizing a deconvolution technique. The addition of non-reacting fine silica to the sample has improved the resolution and the reproductibility of the peaks significantly. Some of the factors that control the peak positions are temperature, concentration of oxygen, particle size, presence of impurities, sample preparation method and the amount and mode of sample spreading in the sample boat. Work is continuing to improve deconvolution of various peaks in the chronogram.

b) Report on desulphurization of high sulphur coals

Various options for improving the existing techniques as well as developing new techniques for desulphurization of high sulphur coals have been studied. These include high intensity high gradient magnetic separation, electrostatic separation, selective biochemical depression of pyrite from coal, development of selective depressants for pyrite in coal, column flotation, and development of the CANMET sulphur-form analyzer. A comprehensive report is being prepared to review the current physical desulphurization technologies and to summarize the results of CANMET's studies.

Future Directions:

As this project will be consolidated into CANMET's Coal Research Laboratories in FY 1990/91, no new activities were initiated in FY 1989/90. A comprehensive project report is being prepared on the High Sulphur Coals Project. It will summarize the results of all activities and will indicate the direction for future R&D.

Outputs:

Patents

- Moon, K.S. and Sirois, L.L., "Method for analyzing different sulphur forms"; Can. Patent No. 1,252,705; April 18, 1989.

- Moon, K.S. and Sirois, L.L., "Method and apparatus for analyzing different sulphur forms"; U.S. Patent No. 4,845,040; July 4, 1989.

MINERAL PROCESSING SUB-ACTIVITY

Process Mineralogy

Project 30.05.02: Mineral Evaluation of Process Products
Project leader : W. Petruk

Objective:

To determine mineral behaviour during processing, by examination of feed and products, in order to define the conditions that grinding circuits, concentrators, hydrometallurgical processes and pyrometallurgical processes must achieve to obtain optimum metal recoveries; and where warranted, to recommend improvements to design and/or operation procedures of mills and processing units.

Highlights and Achievements:

a) Measuring mineral liberations

When evaluating the behaviour of minerals during mineral beneficiation it is necessary to define the term "liberated mineral grains" because concentrates tend to recover both partly and fully liberated grains. It was determined that zinc concentrates tend to recover particles with more than 70 vol % sphalerite, copper concentrates recover particles with more than 50 vol % chalcopyrite, and iron concentrates recover particles with more than 90 vol % hematite. A correlation between particle type and concentrate grade was established.

b) Mineralogical characteristics that affect recoveries

i) Sphalerite, galena and cassiterite

Mineralogical characteristics that affect sphalerite, galena and cassiterite recoveries from volcanogenic ores by mineral beneficiation were determined. Characteristics that affect sphalerite recoveries are liberations, sizes of liberated grains and, possibly, surface effects such as coatings or sphalerite compositions. Most volcanogenic ores contain massive sphalerite, interstitial sphalerite, and sphalerite inclusions in pyrite grains. The ores require a primary grind to liberate the massive sphalerite, and a regrind to liberate small interstitial sphalerite grains. Sphalerite inclusions in pyrite are generally non-recoverable. Liberated sphalerite grains that range from 4 to 150 micrometres in diameter float readily in most conventional flotation cells. Regrinds to 80% minus 400 mesh, which are required for liberating fine-grained sphalerite, produce some slimes. About 25 to 50% of the minus 4 micrometre liberated sphalerite grains tend to be lost to tails. A significant proportion of the 4 to 150 micrometre liberated sphalerite grains from some complex base metal ores is lost in the copper concentrate. The reason is unknown.

The galena in volcanogenic base metal ores is generally very fine grained and is poorly liberated in both primary and regrind mill discharges. Consequently low grade lead concentrates (30 to 35 wt % Pb) are produced to obtain high lead recoveries. The lead concentrates contain many impurities including high amounts of pyrite and sphalerite and small amounts of Cu-, As, Ag- Bi-, and Se-bearing sulphides. Galena tends to break readily into slimes during grinding and slimed galena grains smaller than 4 micrometres in diameter tend to be lost to the tailings.

Most of the cassiterite in volcanogenic base metal ores is in grains that are smaller than 18.5 micrometres in diameter. A high proportion (around 60%) of the cassiterite is liberated during grinding because it occurs in sphalerite which tends to break along cleavage planes and release the cassiterite. Most of the liberated cassiterite is in grains that are too small to be recovered by gravitational methods. Cassiterite flotation from a finely-ground pyrite-rich product is difficult.

ii) Iron ores

Recovery of hematite from the iron ores in the Labrador Trough (Iron Ore Company of Canada, Wabush Mines Limited and Quebec Cartier Limited) was investigated. The main concentrating unit for recovering the hematite is spirals. Spirals recover hematite particles in the size range of 100 to 600 micrometres very efficiently, but the efficiency drops rapidly for finer grained particles. The ores from the Labrador Trough tend to break along grain boundaries during grinding and to produce free particles of the same grain size as in the ore. The Quebec Cartier ore is coarse-grained and about 85% of the hematite is recovered. The Iron Ore Company of Canada and Wabush Mines have finer grained ores and are obtaining lower recoveries from their spiral circuits. Wabush Mines have a high intensity magnetic separator in their circuit to recover some of the fine-grained liberated hematite from the spiral tails, whereas the Iron Ore Company of Canada does not. Research work is recommended for the Iron Ore Company of Canada.

iii) Gold

The behaviour of gold during flotation of the volcanogenic ore from the Trout Lake deposit, Flin Flon, Manitoba was investigated. All the liberated and partly liberated gold grains plus the gold attached to chalcopyrite was recovered in the copper concentrate. The tails from the copper circuit were fed to a zinc circuit which acted as a scavenger and recovered small unliberated gold grains that had a relatively large exposed surface. The gold lost to the tails included minute exposed gold grains (< 1.5 micrometres in diameter), gold inclusions (< 1 micrometre) in pyrite, and invisible gold in pyrite. None of the gold in tails is recoverable by flotation.

Future Directions:

A mathematical liberation model that accurately predicts liberations from image analysis data of unground materials will be developed for incorporation into a model for flowsheet design. The liberation model will predict liberations that would be obtained at particular grinds, and the information will be used for designing flotation circuits which will produce the desired concentrate grades.

A computer will be interfaced with the image analyzer to accept image analysis data for proportions of free and unliberated grains in mill products from a circuit. The liberation data will be input by computer into a BILMAT program which will calculate recoveries of both free and unliberated grains at each point in the flowsheet.

Outputs:

Contracts

- Reqn. 4-9232 "Mineralogical studies of potash deposits"; New Brunswick - Research and Productivity Council. S.A. - W. Petruk.

- Reqn. 4-9235 MDA, "To determine mineralogical characteristics that affect the behaviour of copper, zinc, lead, silver and gold in copper, zinc and lead concentrates from Cu/Zn/Pb ores in Manitoba, Phase (1a) mineralogical characteristics of Trout Lake Ore, Phase (1b) behaviour of Trout Lake ore during beneficiation"; Hudson Bay Mining and Smelting Co. S.A. - W. Petruk.

Publications

- Petruk, W., "Mineralogical characteristics that affect recoveries of sphalerite from volcanogenic base metal ores"; Lead-Zinc '90; AIME/TMS, Warrendale, PA.; pp 655-664; 1990.

- Petruk, W, Chen, T.T. and Wilson, J.M., "Mineralogical characteristics that affect recoveries of galena from base metal ores"; Lead-Zinc '90; AIME/TMS, Warrendale, PA; pp 665-672; 1990.

- Petruk, W., "Mineralogical characteristics that affect recoveries of cassiterite from the base metal ore of Kidd Creek Mines in Ontario"; Lead-Zinc '90; AIME/TMS, Warrendale, PA; pp 673-679; 1990.

- Petruk, W., "Measurements of mineral liberation in connection with mineral beneficiation"; Process Mineralogy IX; AIME/TMS, Warrendale, PA; pp 33-36; 1990.

- Petruk, W., "Image analysis evaluation of mineral behaviour during a laboratory flotation test of the zinc-lead volcanogenic ore from the Faro deposit, Yukon"; Process Mineralogy IX; AIME/TMS, Warrendale, PA; pp 37-48; 1990.

- Healy, R.E. and Petruk, W., "Behaviour of metallic minerals in the HBMS circuit"; Process Mineralogy IX; AIME/TME, Warrendale, PA; pp 49-60; 1990.

- Coleman, M.M., Gilders, R.D., May, R.A., Melluish, J.M., Petruk, W. and Surges, L.J., "An investigation of the behaviour of free and unliberated mineral particles in the Brunswick Mining and Smelting Corporation Limited concentrator"; Process Mineralogy IX; AIME/TMS,Warrendale, PA; pp 71-80; 1990.

- Petruk, W., "Evaluation of the concentrator of Iron Ore Company of Canada by image analysis and materials balancing techniques"; Process Mineralogy IX; AIME/TMS, Warrendale, PA; pp 111-118; 1990.

- Healy, R.E. and Petruk, W., "Petrology of Au-Ag-Hg alloy and 'invisible gold' in the Trout Lake massive sulfide deposit, Flin Flon, Manitoba"; Can. Mineralogist; in press.

Fig. 1. Operating image analyzer.

Project 30.05.03: Mineral Characterization of Ores
Project leader : J. F. Cabri

Objective:

To assist in the development and processing of Canadian mineral resources including various large tonnage, low grade and complex deposits of metallic minerals and industrial mineral occurrences by assessment of the mineralogy, valuable element distribution, and probable liberation characteristics directed toward the improved recovery of the contained minerals. To evaluate, test and develop advanced analytical instrumentation required to perform the mineralogical examinations.

Highlights and Achievements:

a) A cost-shared, cost-recovery agreement with Galactic Resources Ltd., Vancouver, on detailed mineralogical assessment of samples from the Wellgreen Ca-Ni-Pt-Pd property was completed. Informal reports have been submitted to the company, several oral presentations have been made and a final report is in preparation.

b) A cost-shared, cost-recovery agreement with the B.C. Ministry of Energy, Mines and Petroleum Resources, Victoria was completed. A British Columbia government report was published including some of the results, oral presentations were made, and a paper for publication in an outside journal is being prepared.

c) A cost-recovery contract was signed to examine the precious metal distribution in Cu concentrates. The work has been initiated and should be complete in May 1990.

d) Detailed cost-recovery proposals were prepared and submitted to two companies in connection with precious metal mineralogy.

e) Aside from cost-recovery work undertaken and completed in this field, mineralogical studies of Canadian rare-earth deposits were focused on the Strange Lake deposit northeast of Schefferville, Quebec. Hecla Mining Company of Canada has entered an agreement with Iron Ore Company of Canada to proceed with metallurgical and marketing studies of the property (N.Miner, Mar. 12, 1990). A three-year cost-shared agreement between Hecla and CANMET for mineralogical studies of the Strange Lake and other rare-earth ores is in its second year of operation.

Outputs:

Contract

- Reqn. 9-9020, "Production and characterization of precious and rare element standards for mineralogical and metallurgical studies"; Surface Science Western. S.A. - L.J. Cabri.

Publications

- Cabri L.J., Chryssoulis S.L., De Villiers J.P.R., Laflamme J.H.G., and Buseck P.R., "The nature of 'invisible' gold in arsenopyrite"; Can. Mineral. 27: 353-362, 1989

- Chryssoulis S.L., Cabri L.J. and Lennard W., "Calibration of the ion microprobe for quantitative trace precious metal analyses of ore minerals"; Econ. Geol.; in press.

- Campbell J.L., Maxwell J.A., Teesdale W.J., Wang J.X. and Cabri L.J. "Micro-PIXE as a complement to electron probe microanalysis in mineralogy"; Nucl. Instr. & Methods in Physics Research; in press.

- Nixon G.T., Cabri L.J. and Laflamme J.H.G., "Origin of platinum nuggets in Tulameen placers: a mineral chemistry approach with potential for exploration"; Exploration in B.C. 1988; B.C. Ministry of Mineral & Petroleum Resources, B-83-89, 1989.

Computer Aided Mineral Processing

Project 30.06.01: Computer Aided Mineral Processing (CAMP)
Project leader : D. Laguitton

Objective:

To provide the technology transfer necessary to improve the recovery and/or value of minerals from the processing of Canadian ores through the application of modelling and simulation of minerals and energy processes, by providing the mineral industry with an easily usable computer methodology for circuit evaluation and optimization.

Highlights and Achievements:

The year 1989/1990 saw the conclusion of a decade of efforts in the complementary domains of process simulation and expert system applications in mineral processing. On one hand, the CAMP software for numerical applications such as material balance and simulation has reached a stage of completion that allowed its successful marketing on a worldwide basis. A modest but very efficient advertising resulted in requests for information and promotional software from some 400 sources in 45 different countries. As a result, some 55 software licences were issued in 12 different countries, for a value of over $100K. The second domain of activity was represented by our third application of expert systems in industrial prototypes. It came to its completion at Kidd Creek Mines, a division of Falconbridge Ltd., in October 1989. The system was designed to perform validation tests on chemical compositions obtained from the on-line X-ray analyzer in the Cu and Zn flotation circuits. Whenever possible, invalid assays were replaced by more reliable estimates. The objective of the project included the assessment of expert system software and the improvement of the plant information data as well as of the automatic process control performance. A Microvax computer was connected to the Modcom computer in charge of process data in the concentrator in order to test the application without affecting the existing control software. The project was completed in October 1989 with a two-day workshop presented jointly by the Kidd Creek Division and CANMET in Timmins. Some 40 people attended, coming from six provinces plus the United States and Mexico.

Future Directions:

Activities of the CAMP Software group for the nineties will proceed from the vantage point reached after a decade of development of various computer techniques applied in mineral processing with a focus on process control and liberation modelling.

Outputs:

Contract

- Reqn. 7-9214, "Development of an expert system for process control in a flotation plant"; Falconbridge Ltd. Kidd Creek Mines Div. S.A. - D. Laguitton.

Ore Dressing

Project 30.13.02: Iron Ore Processing
Project leader : W.H. Cameron

Objective:

To maintain the viability and competitiveness of the Canadian iron ore industry by identifying and investigating methods to increase recovery, improve grade and quality of ore concentrates and pellets, reduce energy costs, improve process control and lessen environmental impact.

It has become increasingly apparent in an iron ore buyer's market that Canada cannot assume that it can compete in any market. High labour and energy costs have made pellets less attractive than sinter feed for a blast-furnace. The Canadian iron ore industry finds itself in a less competitive position than before. There is a need to improve efficiency, reduce energy costs and improve product quality and recovery.

Highlights and Achievements:

a) Mill recovery prediction from blast-hole cuttings

A down-hole analyzer, jointly developed by CANMET and the Geological Survey of Canada, will be tested this summer at Wabush, Carol Lake and Q.C.M. Mt. Wright. Core from a diamond drill hole from each property will be correlated with readings from the down-hole analyzer. If the correlations are satisfactory, the analyzer will then be commercialized for use in blast holes to predict iron recoveries from blocks.

b) Enhanced dewatering of Q.C.M. iron ore concentrate

Numerous laboratory filtration tests have been carried out to study the effect of low temperature steam (100°C) in conjunction with five different surfactants, in order to lower moisture content. Results have been so promising (moisture content lowered by 25 to 30%) that a patent search in both Canada and the United States was initiated and steps have been taken to ensure patent protection for this technology. Both Quebec Cartier and Wabush mines have expressed their interest in testing this innovative technology.

c) Iron ore recovery at Wabush Mine

Pilot plant scale tests at the Scully Mine concentrator have been completed. Changes introduced to the flowsheet, as a result of Phases I and II of this project, have increased the overall weight recovery of the pilot circuit by about 1%. When introduced to other mill lines of the concentrator, this improvement will result in a benefit of about $600K per year. Indications are that before this project is completed this result might be further improved.

An expert control system is being developed which would include the grinding/classification/spiral/prototype circuit. The pilot circuit has been equipped with measuring and other control instrumentation and work on implementing software is in its final stage. It is expected that circuit optimization resulting from this work will lead to further savings.

d) Circuitry instrumentation and process control

CANMET, Quebec Cartier Mining and the Iron Ore Company of Canada along with two major equipment suppliers have entered into a joint agreement to optimize some of the current practices and flowsheets of these producers through the use of instrumentation and process control. The work is being carried out in the CANMET pilot plant.

Ongoing projects include fine iron recovery in the rougher spiral circuits and the acquisition or development of instrumentation for real time control of fluxed pellet feed.

e) Other activities

The Iron Ore Technical Task Force Committee held a meeting January 19, 1990 in Ottawa.

W. Cameron was asked to be organizing chairman for a symposium on "Processing of Iron Ores" which will be a part of the CIM 29th Annual Conference of Metallurgists to be held in Hamilton, Ontario, August 26-30, 1990.

Future Directions:

Work will continue on the three-year joint agreement mentioned under "Circuitry instrumentation and process control". Other elements to be studied include: optimization of autogenous grinding circuit, grind control in pelletizing circuit, reduction of SiO_2 to 3-3.5% in concentrate, SiO_2 control in spiral circuit, on-line SiO_2 measurement using X-MET.

Through the "Iron Ore Technical Task Force Committee", a current awareness of new problems will be maintained where MSL assistance would be appropriate.

Outputs:

Contracts

- Reqn. 7-9174 MDA, "To improve iron ore recovery at the Wabush Scully Mine"; Labrador, Phas IV. S.A. - M. Stefanski.

- Reqn. 9-9132, "Design and install a 60 cm SAG mill circuit"; University of British Columbia. S.A. - W. Cameron.

Project 30.13.04: Energy Conservation in Industrial Mineral Processing
Project leader : F.R. Campbell

Objective:

To increase the efficiency of energy use in the industrial minerals sector through the identification of energy intensive operations; identification, development and testing of improved technology; and transfer of that technology to industry.

Highlights and Achievements:

a) Comminution

The work in this area was started in 1983 as a multi-phased study carried out entirely under contract. Phase I included studies on 10 different industrial minerals in the development of a database and unit energy consumption. Phase II involved the establishment of particle size measurement and monitoring methodology, which is critical in the search for reduction in energy costs. Phase III was to develop a pilot scale system to demonstrate the new technology for various industrial minerals. Phase III was composed of nine activities, of which three were abandoned due to lack of participation from industry. Activity 2 - Improved Classifiers was completed this year and ended the multi-phase study. Seminars will be held during this coming fiscal year to report on the overall activity.

b) Fluoride emission control from clay kilns

No activity is reported in this area as industrial partnership, essential to technological transfer, was not found. Therefore this area is terminated.

c) Supplementary cementing materials

The several investigations under contract which have been catalogued in this project are covered under Project 30.37.01 - Use of Supplementary Cementing Materials in Concrete.

Future Directions:

Because energy conservation and environmental protection are now considered in most of the activities and projects within MPL, the elements of this project are now integrated into other projects in existence in MPL.

Outputs:

Contract

- Reqn. 4-9263, "Energy conservation in comminution of industrial minerals, Phase III: Activity 2 - Examination, study and analysis of the state of development of high efficiency air classifiers for cement and other mineral grinding circuits"; Canada Cement Lafarge Ltd. S.A. - T. Cienski.

Project 30.13.05: Beneficiation/Grinding Studies of Industrial Minerals
Project leader : D.G. Feasby

Objective:

To continue to identify problems and opportunities in industrial minerals processing, and to develop and improve processing methods for the recovery of minerals and metal products acceptable to the marketplace, and to respond to needs of industrial clients in materials handling and environment-related concerns.

Highlights and Achievements:

Summary reports were completed on silica, gypsum/anhydrite, graphite, and mica/vermiculite. These reports summarize previous work at CANMET and current activities across Canada. At the end of fiscal year 1990/91 fifteen reports covering 23 minerals will have been published.

As in previous years, several beneficiation studies were conducted for and in cooperation with a variety of industrial and provincial government clients. Work was done on wollastonite, mica, graphite, garnet, calcite and various heavy minerals such as ilmenite. What was new about the work was the strong interest by industrial clients in the recycle, separation and handling of industrial wastes. These industrial wastes are usually dry, and the separation and processing techniques used in industrial minerals are often applicable. For example, a project on the separation of metal oxide from metal in a steel plant waste product uses the difference in brittleness of oxide and metal to preferentially grind metal oxide, and air swept separators can be used to separate the two materials. Spent electrolytic cell lining from an aluminum producer contains various metallic and non-metallic materials. In cooperation with the client, a prototype separator was developed that can separate materials based on electrical conductivity. Work was also done on the recycle of foundry sand and of waste fibreglass.

The amount of unsponsored work declined further during 1989/90, and some 25 cost recovery projects were done. Routine mineral beneficiation testwork was routinely referred to commercial laboratories.

Future Directions:

The Industrial Minerals Laboratory will continue to provide a national information function through dissemination of technical information through personal contact and production of Summary Reports. Where special capabilities exist in the laboratory, work with industrial clients will continue. The laboratory will continue to develop expertise in the beneficiation of the high aspect minerals such as wollastonite and mica.

Outputs:

Contracts

- Reqn. 7-9005 MDA, "Study of the production of barium chemicals for the Lake Ainslie barite deposit"; Conwest Exploration. S.A. - D.G. Feasby.

- Reqn. 9-9211, "Moisture isotherms on potash products"; Potash Corporation of Saskatchewan. S.A. - D.G. Feasby.

- Reqn. 9-9210, "Extender oils in potash floatation"; Potash Corporation of Saskatchewan. S.A. - D.G. Feasby.

Reports

- Andrews P.R.A., "Benefication of Canadian graphite ores"; Division Report MSL 89-121 (OP&J); presented at the 92nd AGM of the CIM; Ottawa; May 1990.

- Mathieu G.I., Provencher R. and Tellier J.G., "Mechanical sorting of aluminum metal from spent potlining"; Division Report MSL 89-103 (OP&J); presented at the 119th Annual Meeting of the AIME; Anaheim, California; February 1990.

- Feasby D.G., "Industrial minerals in Canada: the Federal-Provincial Agreements"; Division Report MSL 89-25 (OP&J).

- Andrews P.R.A. and Collings R.K., "Benefication of barite: a review of processing studies at CANMET"; Division Report MSL 88-62 (J).

- Andrews P.R.A., "Benefication of Canadian wollastonite ores"; Division Report MSL 89-60 (OP&J).

- Andrews P.R.A., "Benefication of some Canadian industrial minerals"; Division Report MSL 88-150 (J).

- Andrews P.R.A., "Pilot-plant treatment of a Quebec talc ore", Division Report MSL 88-95 (J).

Project 30.13.07: Beneficiation of Complex Ores
Project leader : T. Cienski

Objective:

To develop new processing and treatment methods for the beneficiation of complex and refractory ores.

It has become increasingly apparent that many high grade and easily liberated ores are being depleted. In order for Canadian mining operations to remain competitive on a world market, it is necessary to develop methods to efficiently treat complex, low grade refractory ores.

Highlights and Achievements:

a) Column flotation

A column flotation R&D program has been initiated to assist the Canadian mineral processing industry to take full advantage of this novel, cost effective technology.

The joint, cost-shared program is coordinated through the Mining Industry Technology Council and brings together skills and experience from industry, universities and government to evaluate:

1. various air sparging systems
2. various column designs
3. circuit configuration using columns
4. the behaviour of minerals in the column froth zone.

The first of the above elements is now being investigated at MSL. It is expected that this work will be completed and the report presented at the end of April 90.

Preparations are under way for testing the "Jameson" flotation cell which will be carried out at the Kidd Creek concentrator.

b) Unit column flotation

An in-house study is in progress to evaluate the applicability of the flotation column to the unit flotation process. There are potential operating and metallurgical benefits in this approach.

A joint R&D program involving CANMET, Lakefield Research and Highland Valley Copper is underway in order to conduct larger scale investigations related to unit column flotation.

c) Tin flotation

Research work to recover tin using newly developed reagents continued. Under selected grinding-regrinding conditions and a carefully controlled reagent and pH regime, a concentrate of 12.4% Sn was obtained from a low grade sample of 0.2% Sn ore originating from East Kemptville, N.S. The company expressed renewed interest in this work and submitted a new sample of higher Sn content. Tests are under way to investigate tin recovery using Briquest as well as Procol reagents, both not yet employed in commercial tin flotation. The 2N - 81 - 25S (Briquest), an aminophosphonic acid, and Procol CA540, a modified sulfo-succinimate, are efficient cassiterite collectors and much cheaper than the SPA (styrene phosphonic acid) presently used at East Kemptville for tin flotation.

Future Directions:

Column research will continue with in-plant testing of spargers and special devices, and with the analyses of column parameters. Pilot-scale work is planned with an oil sands processor and with a niobium producer. A major project has commenced on the selective flotation of sulphide minerals, mainly on reducing the reporting of one metal to another metal concentrate. Initial work is focused on copper-zinc ores, and is to be followed with examination of copper-lead-zinc ores. Pulp electrochemical potential control is to be a major component of this research.

Ceramics

Project 30.29.01: Advanced Ceramic Materials
Project leader : T.A. Wheat

Objective:

a) Materials survey

To survey and review the opportunities and limitations of developments in the broad field of advanced ceramics with respect to the Canadian scene.

b) Thermal characterization

To develop methodology for the independent direct determination of each of the major thermophysical parameters: specific heat, thermal conductivity and thermal diffusivity.

c) Mechanical characterization

To establish the methodology for the determination of the mechanical properties of ceramic materials such as hardness, toughness, modulus of rupture and creep.

Highlights and Achievements:

a) Materials survey

During 1989, a series of studies dealing with both present market trends and also with specific technical areas that are relevant to the Canadian environment was completed. Initially, a survey of the global trends in ten selected topics as revealed by the patent literature was completed. It shows that opportunities exist for Canadian developments in some areas such as sol-gel technology, metal-organic ceramic precursors, wear resistant materials, selected dielectrics, etc.

In support of this study, two other topics were addressed: the opportunities for metal-organics and the benefits of using inorganic chemical processing in producing high quality ceramic products. All three studies have been completed and the material documented: the results of each study are to be placed in the public domain.

b) Thermal characterization

The present period concluded an extensive program to develop the capability in CANMET to directly and independently measure the principal thermophysical properties of ceramics. Currently, the thermal expansion, specific heat, diffusivity, and conductivity can be determined using computer-controlled equipment custom-build to CANMET concepts and specifications.

c) Mechanical characterization

During 1989, delivery was taken of a testing frame which was built in Canada and which offers all the needed capabilities for the characterization of ceramics, i.e., the ability to operate at very low strain rates (1 μm/min) and of temperatures over 1500°C. Designed and built in Toronto to CANMET specifications, the system is comparable with systems available outside the country at over double the cost. This equipment augments existing capability which uses indentation techniques to determine hardness and toughness.

Future Directions:

a) Materials survey

It is anticipated that specific topics for further development will arise with industrial collaborators and that such surveys in the future will not be conducted.

b) Thermal characterization

The project was completed at the end of 1989.

c) Mechanical characterization

The project was completed in 1989.

Outputs:

Publication

- Pouskouleli, G., "Metallorganic compounds and preceramic materials II"; Ceramics International 15:255-270; 1989.

Report

- Pouskouleli, G. and Wheat, T.A., "Advanced ceramics: International research trends"; Division Report MSL 89-138 (OP&J); presented at the 87th Annual Meeting of the Canadian Ceramic Society; Ottawa; February 1989; submitted to Jour. Can. Ceram. Soc.

- Pouskouleli, G., Wheat, T.A., Quon, D.H.H. and Ahmad, A., "Advanced ceramics by hydrometallurgical processes"; Division Report MSL 89-88 (OP&J); submitted to Amer. Soc. for Metals.

Project 30.29.02: Toughened Ceramics
Project leader : A.K. Kuriakose

Objective:

To develop superior, wear-resistant ceramics for commercial applications, in cooperation with Canadian industry.

The use of ceramics in many wear resistant applications, such as cutting tools for modern numerically controlled machines, sand blast nozzles, ball bearings, elbows, valves and scraper blades for equipment handling solids and slurries in mining and other industries, etc., is extremely advantageous when compared with traditional metallic materials that are currently being used. For such applications, increased toughness (resistance to brittle cracking) of the ceramic materials is a necessity. Zirconia transformation toughening is one of the efficient ways of increasing the toughness of brittle hard ceramics; CANMET's program is aimed at producing Canadian capability in competing in the fast developing world market (worth billions of dollars) in these products.

Highlights and Achievements:

a) Hydrothermal synthesis of zirconia

The properties of the zirconia used for the toughening of ceramics are extremely important in determining the final degree of toughening of a ceramic that is achievable. A hydrothermal process has been devised for the preparation of submicrometre, uniformly sized powders of zirconia, which when used for toughening other ceramics, produces superior products.

b) Modified zirconia-toughened alumina

The wear resistance of alumina itself can be improved by the introduction of certain additives which influence its crystal chemistry. The toughening of such modified alumina by the zirconia transformation technique should produce wear resistant materials which are even more durable than plain zirconia-toughened alumina. A preliminary investigation has been undertaken to screen such products and the results are encouraging.

c) Zirconia-toughened mullite

Hydrothermally synthesized zirconia has been used to produce toughened mullite. Preliminary results show that the new products are stronger and tougher then products made using traditional zirconia.

Future Directions:

Development of the materials and processes indicated above will continue to show proof of principle. The technology will then be transferred through collaborative effort to the Canadian industrial partners.

Outputs:

Publications

- Quon, D.H.H., Wang, S.S.B., Aota, A., Wheat, T.A., Kuriakose, A.K. and Torrie, G., "Hydrothermal synthesis of zirconia and preparation of zirconia-mullite composites"; Interceram 38:15-17; 1989.

- Puskouleli, G., "Metallorganic compounds and preceramic materials II"; Ceramics International 15:255-270; 1989.

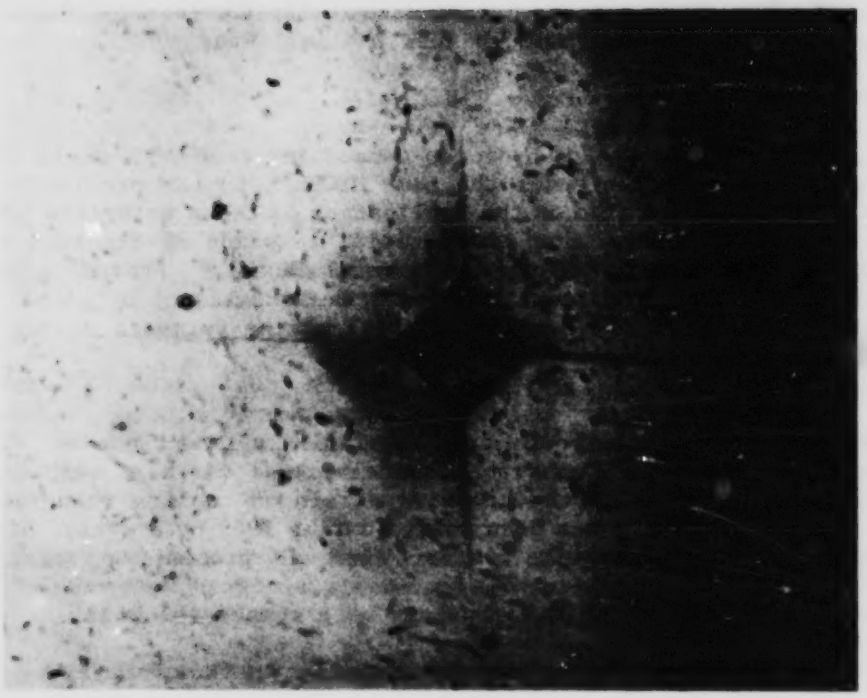

Fig. 2. Optical micrograph of the polished surface of CANMET-developed toughened oxide ceramic showing the crack formation that occurs at the corners of a diamond indenter used to determine fracture toughness.

Projects 30.29.03: Functional Ceramics
Project leader : A. Ahmad

Objective:

To develop a range of dielectric materials for various sensor applications in collaboration with industrial partners.

Highlights and Achievements:

a) Piezoelectrics and electrostrictors

The focus of the work has been the development of a variety of piezoelectric and electrostrictive materials by several different processes. Already, materials and processes have been discovered which yield a product having a dielectric

constant > 20,000 at a frequency of 1 kHz. Work will continue in 1990 in which the apparent controlling process parameters are first screened and then optimized using statistical design techniques.

b) Solid electrolytes

Following the development of a hydrogen-conducting composite dielectric and its patenting and registration under the name HYCERAM in the previous period, the work in 1989 has concentrated on the application of these materials in a hydrogen sensor. It has been shown that the material responds as expected in a sensor over hydrogen concentration changes of several decades. Prototype sensors have been produced in collaboration with industry and trials are to be made in sensing the hydrogen content of off-gases from steel-making furnaces during 1990.

c) Pyroelectrics

One of the most sensitive pyroelectric materials is lead titanate. However, it is difficult to exploit in monolithic form because the high anisotropy of the basic crystal lattice leads to excessive strain on cooling from the sintering temperature. This problem has been solved during 1989 by a series of studies on the crystal lattice changes with compositional and processing variations. As a result, a royalty-bearing licence agreement was signed between CANMET and the private sector to exploit this technology on a commercial basis.

In order to minimize the difficulties of transferring from laboratory to production, the work is continuing using statistical design (SD) techniques in which 22 parameters in a flow sheet (> $4x10^6$ trials) will be screened for their importance and probable interactions on the production line - the use of SD will dramatically reduce the work required to a manageable 32 trials using a Taguchi design.

Future Directions:

It is expected that development and optimization of these materials will continue with industrial partners.

Outputs:

Patent

- Kuriakose, A.K., Wheat, T.A., Ahmad, A., Canaday J.D. and Hanson, A.J., "Bonded hydrogen conducting solid electrolytes"; Can. Patent No. 1,262,041; October 3, 1989.

Publications

- Canaday, J.D., Kuriakose, A.K., Wheat, T.A., Ahmad, A., Gulens, J. and Hildebrandt, B.W., "Bonded solid proton conductor/platinum electrochemical cells"; Solid State Ionics 35:165-175; 1989.

- Gulens, J., Hildebrandt, B.W., Canaday, J.D., Kuriakose, A.K., Wheat, T.A. and Ahmad, A., "Influence of water on electro-chemical response of a bonded protonic conductor"; Solid State Ionics 35:45-49; 1989.

- Canaday, J.D., Wheat, T.A., Haley, M.P. and Joyce, I.H., "A morphollogical investigation of electrodes for solid electrolytes"; J. Mat. Sci., 24:3621-3634; 1989.

Reports

- Ahmad, A., Besso, K., Chehab, S.F., Wheat, T.A. and Napier, D., "Chemical processing of modified lead titanate"; Division Report MSL 89-20 (OP&J).

- Chehab, S.F., Canaday, J.D., Kuriakose, A.K., Wheat, T.A. and Ahmad, A., "A hydrogen sensor using a bonded hydronium nasicon solid electrolyte"; Division Report MSL 89-104 (J); presented at the 87th Annual Meeting of the Canadian Ceramic Society; Ottawa; February 1989; submitted to Solid State Ionics.

- Canaday, J.D., Chehab, S.F., Kuriakose, A.K., Wheat, T.A. and Ahmad A., "Protonic conductivity of bonded hydronium nasicon"; Division Report MSL89-105 (J).

- Canaday, J.D., Wheat, T.A., Ahmad, A., Kuriakose, A.K., Kwong, M., Jacobs, J.K., Das Gupta, S. and Wilson, E.J., "A transient-analysis method for electrochemical cells"; Division Report MSL 89-106 (J).

- Ahmad, A., Kuriakose, A.K., Bedard, P., Rolko, V. and McDonald, A.G., "FTIR spectral studies on the modified lead titanate ceramics"; Division Report MSL 89-130 (IR).

- Ahmad, A., Kuriakose, A.K., Canaday, J.D., Wheat, T.A. and Chehab, S., "Alkaline earth and rare earth doped lead titanates"; Division Report MSL 89-131 (IR).

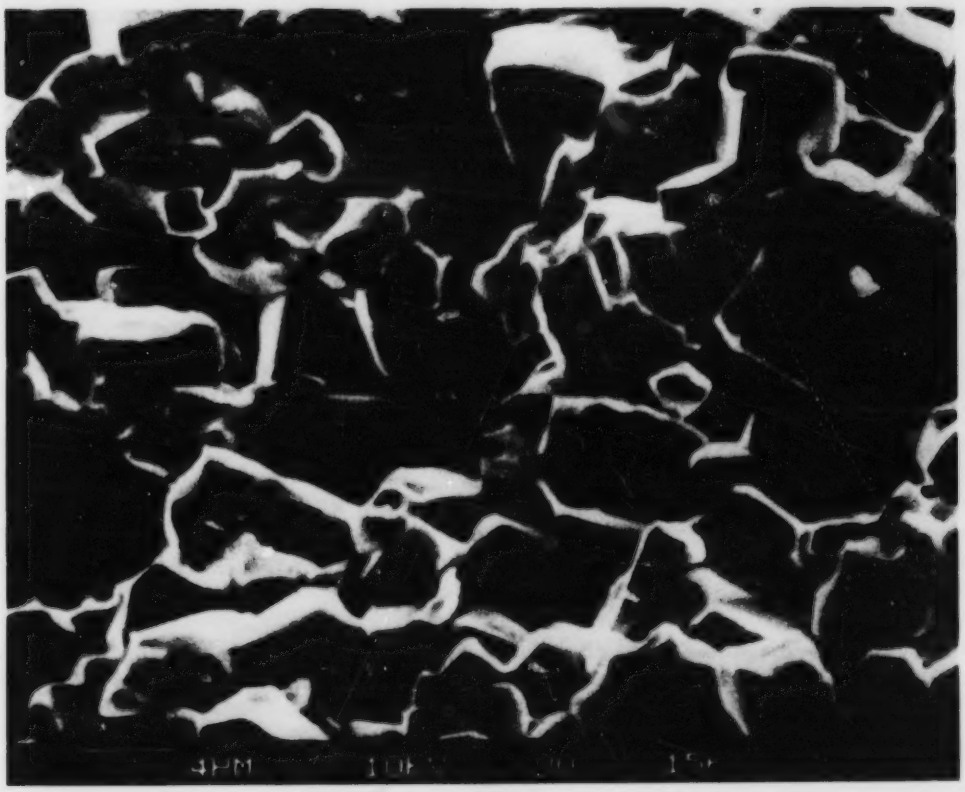

Fig. 3. SEM micrograph of the fracture surface of a sintered piezo-electric ceramic monolith based on a doped lead titanate developed at CANMET showing a relatively fine-grained and uniform micro-structure.

Project 30.29.04: Non-oxide Ceramics
Project leader : A.K. Kuriakose

Objective:

To synthesize and fabricate silicon carbide in different morphological forms and to establish optimum conditions for the fabrication of silicon carbide-based ceramics for electrical and ultra high temperature structural applications.

Silicon carbide is one of the very few materials that retain high strength and rigidity to about 1600°C and this coupled with high thermal shock resistance and

high thermal conductivity makes it one of the most promising materials for applications such as in ultra-high temperature gas turbines and internal combustion engine parts. However there are many problems with respect to both the synthesis and fabrication of high quality silicon carbide products. CANMET's program is directed to solve these problems in cooperation with participating Canadian companies.

Highlights and Achievements:

a) Synthesis of reactive ultra-fine silicon carbide

Problems in the scale up of the silica-carbon reaction producing ultra fine silicon carbide powders have been recognized and solutions to some of these problems have been devised. Methods are being formulated for a large scale manufacturing process which requires specially designed high temperature furnaces.

b) Analysis of free carbon and free silica in silicon carbide

A simple method has been developed for the determination of free carbon and free silica in finely divided silicon carbide. Conventional methods yield erratic results when applied to fine silicon carbide. Other available methods are much more complicated and/or expensive.

c) Silicon carbide sintering

Using statistical design, a large number of materials have been screened as sintering aids for silicon carbide, and a few significantly active agents have been identified. Work is underway to produce sintered silicon carbide of near theoretical density with the minimum amount of additives. Minimization or elimination of sintering aids is essential for the utilization of the best high temperature properties of silicon carbide.

Future Directions:

Development of manufacturing and sintering techniques and determination of strength and creep characteristics of the products for ultra-high temperature use will continue. The technology will be transferred to collaborative private industry.

Outputs:

Publication

- Pouskouleli, G., "Metallorganic compounds and preceramic materials I. Non-oxide ceramics"; Ceramics International 15:213-229; 1989.

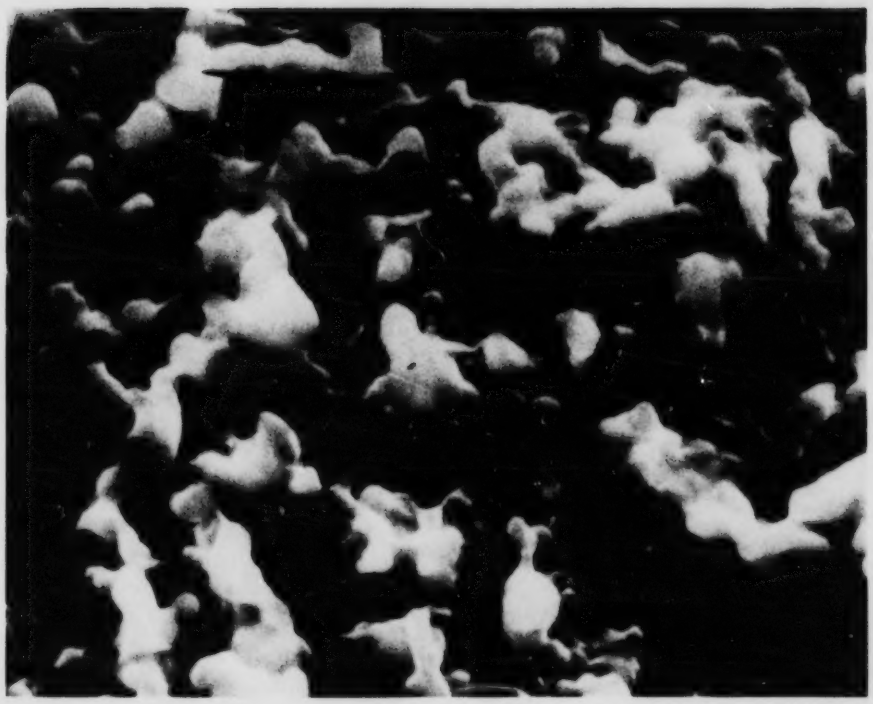

Fig. 4. SEM micrograph showing the growth on a carbon substrate of sub-micrometre beta-silicon carbide powder developed as part of CANMET's program in structural ceramics.

Project 30.29.05: Refractories
Project leader : T.A. Wheat

Objective:

To develop an understanding of the degradation mechanisms that operate in selected refractories under operating conditions in order to assist Canadian steel-makers to increase the lifetime of the refractories in their operations.

Highlights and Achievements:

a) Behaviour of MgO-C refractories

During 1989, work continued on a detailed examination of carbon-containing magnesium oxide refractories especially with respect to the loss of carbon under non-oxidizing conditions. The behaviour of these materials and the formation of low concentrations of carbides in the brick were reported in a paper presented

to the first Unified International Technical Conference on Refractories (UNITCER) in Anaheim, October 1989.

b) Behaviour of rebonded chrome-magnesia refractories

The work on these materials, which was initiated in 1988, was concluded during 1989. In essence, the mechanisms of degradation that occur at high temperature when these materials are used to line secondary steel-making ladles was determined and documented. The work was conducted in collaboration with a major steel maker.

Future Directions:

The technical capability in this field will be retained and probably expanded under the C-Cubed project in which specific activities are undertaken at the request of industry.

Outputs:

Publications

- Quon, D.H.H. and Bell, K.E., "Performance of rebonded fused-grained chrome-magnesia refractories in secondary steel-making ladles"; CIM Bull. 82:90-94; 1989.

- Wang, S.S.B., Quon, D.H.H., Aota, J. and Kuriakose, A.K., "Degradation of magnesia-carbon bricks in argon at high temperature"; Proceedings of the 1st Biennial Unified International Conference on Refractories, ed. L.J. Trostel; published by the American Ceramic Society; 1989; in press.

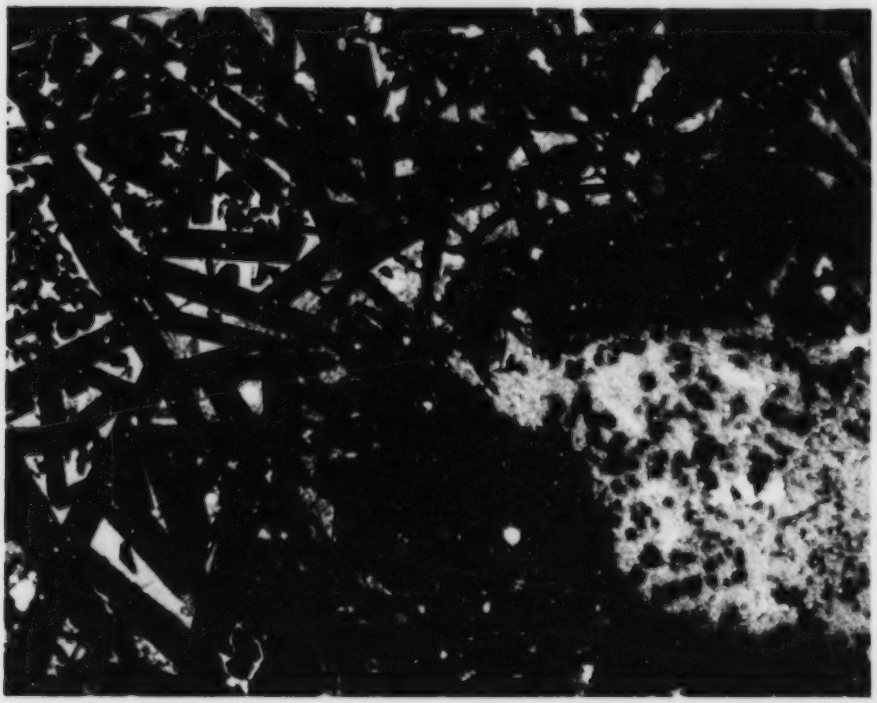

Fig. 5a. SEM micrograph of a polished section of slag build-up material taken from a commercial ladle showing the presence of lath-shaped recrystallized alumino-silicate (Mullite), complex spinels and calcium aluminates. The build-up can be so severe that the useful volume of a ladle is drastically reduced in a plant. (Figure 5b is the same subject, but at a different contrast.)

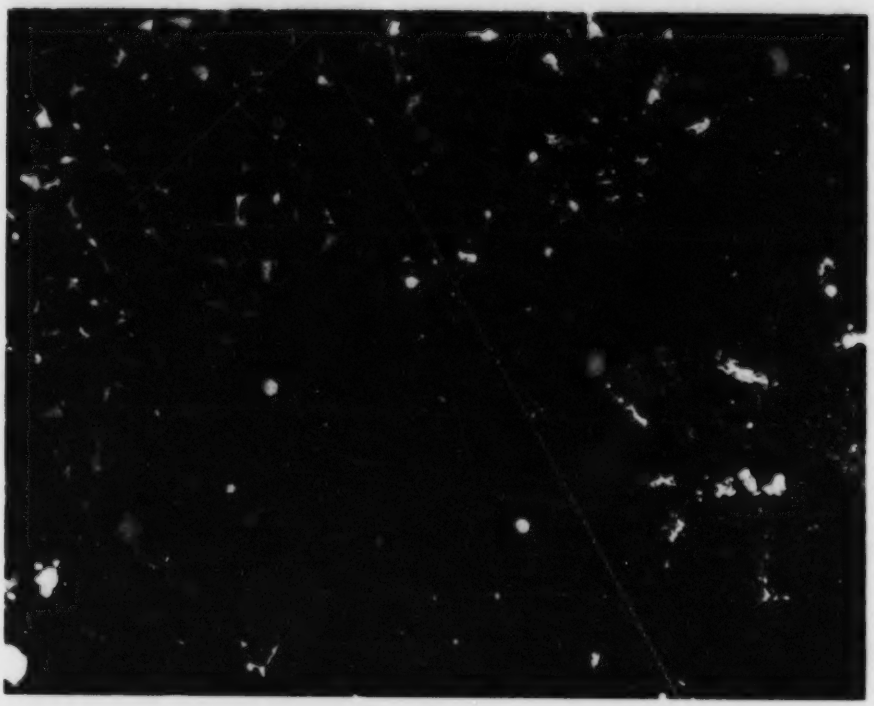

Fig. 5b. Same subject as Fig 5 a, but at a different contrast.

Project 30.29.06: CANMET Ceramics Consulting (C-Cubed)
Project leader : T.A. Wheat

Objective:

The provision of consulting facilities and services to industry in which the objectives of the member companies are met through a program that minimizes paperwork on either side and offers maximum flexibility to the members.

Highlights and Achievements:

This program was launched in October 1989 in recognition of the needs and realities of the Canadian ceramics industry which is characterized by having many relatively small (< 50 employees), cash-poor companies which find it difficult to enter into major development programs even on a cost-shared basis.

The mechanism by which the program operates depends on member companies purchasing "time credits" with CANMET which they then redeem over the course of

a year as they see fit. In this manner, the companies have maximum flexibility: they can switch from a literature survey, to failure analysis, to statistical design all within a single initial time credit of 50 hours without the need for establishing contractual obligations initially, and without the need for major paperwork should they wish to redirect the work.

By the end of the year, four members had already been signed up to C-Cubed. Their interests cover the spectrum of the ceramics field including refractories, structural and functional materials. At the request of the members, their names are withheld from this report.

Future Directions:

The Ceramics Section will provide a wide range of CANMET capabilities to the Canadian industry on a cost-recovery basis.

Concrete Technology

Project 30.37.01: Use of Supplementary Cementing Materials in Concrete
Project leader : V.M. Malhotra

Objective:

To develop data on mechanical and elastic properties and durability of portland cement and portland cement concrete incorporating up to 65% less energy intensive materials, such as granulated blast-furnace (B.F.) slag, fly ash, silica fume and limestone dust for applications in Canada.

To conserve resources and energy it is imperative that less costly and less energy intensive materials be used in the production of portland cement and portland cement concrete. The most promising of the less energy intensive materials for replacing cement are granulated slag, fly ash and silica fume. The energy required to produce granulated slag is estimated at only 25% of that for portland cement, and fly ash and silica fume are industrial waste products. Thus, their use has major environmental implications as well. Since slag and fly ash from different sources have unique properties depending upon the raw materials used, it is essential that investigations be performed to obtain long-term performance data on their use, with and without high-range water reducers, in concrete under Canadian climatic conditions.

Highlights and Achievements:

a) High-volume fly ash concrete

Investigations were continued to develop the data bank on the properties of high-volume fly ash concrete. The investigation was extended to include fly ash from other sources in addition to one from Lingan, N.S. A large number of concrete

mixtures were made of varying proportions and at three different cement contents. Specimens were cast for determining mechanical properties and durability of concrete. Test data show that to some extent, the properties of high-volume fly ash concrete are dependent upon the type of fly ash used. All concretes had excellent durability, as characterized by permeability and abrasion resistance.

However, the performance of the high-volume fly ash concrete, regardless of the source of fly ash, was very poor in deicing scaling tests, and therefore the use of this type of concrete is not recommended for situations where concrete is to be exposed to repeated applications of deicing chemicals.

Investigations were also commenced to determine the performance of high-volume fly ash concrete under sulphate attack. A number of concrete mixtures were made and test prisms were cast for immersion in 5% sodium sulphate solutions. The test prisms are being monitored at frequent intervals using NDT methods and measuring changes in length. The tests will be continued for several years and progress reports will be issued at yearly intervals.

b) High-strength concrete

Research on mechanical properties and durability of high-strength concrete incorporating supplementary cementing materials was continued. Several reports on the subject have been issued. The use of superplasticizers and supplementary cementing materials become essential for concrete with water-to-cementitious ratios of less than 0.25.

Drilled cores are being taken at intervals from large concrete blocks which were cast in Toronto in a cost-shared program with Trow Ltd., Toronto. Two-year core data indicate that concrete incorporating silica fume do not gain much in strength after about one year whereas control concrete and high-volume fly ash concrete show continuous gain in strength up to two years. Drilling of cores from these blocks will be continued for another 5 years. A report has been issued and will be presented at an international conference.

The issue that non air-entrained high-strength concrete is durable in freezing and thawing environments has not been resolved. Additional concrete mixtures have been made at W/C of 0.21, 0.25 and 0.28 and specimens from these mixtures will be subjected to ASTM freezing and thawing test C 666 Procedure A. An outside laboratory will be used to duplicate specimens.

c) Activation of blast-furnace slag and fly ashes

Exploratory studies on the mortars performed in 1988 were extended to concrete. The concrete investigation incorporated sodium silicate as an activator but did not contain any portland cement.

The five concrete mixtures studied were proportioned using sodium silicate and small amounts of hydrated lime. The water-to-binder ratio of the mixtures ranged from 0.34 to 0.50. The air-entrained concrete produced satisfactory workability. The 1-day and 28-day compressive strengths of the concretes ranged from 20.4 to 38.9 MPa and from 45.5 to 59.6 MPa, respectively. The 7- and 14-day flexural strengths were of the order of 5 MPa.

A two-year contract worth $276K was awarded to Handy Chemicals Ltd., La Prairie, Quebec to investigate the activation of fly ashes and slags on a 50/50 funding basis. Also, small contracts were awarded to IRC/NRC and Matex Inc. (Toronto) to look into special aspects of the activation.

d) Other activities

Several cost recovery investigations which were undertaken in 1988 were continued. These dealt with the development of data on mechanical properties of fibre-reinforced high-volume fly ash shotcrete for use as a capping (sealant) for pyritic slate outcrops at Halifax airport (for Transport Canada), the development of engineering data on foam concrete (for Anthes Equipment Ltd., Toronto) and the utilization of fluidized bed combustion waste as a cementitious material (for L.E. Shaw Ltd., Halifax). The investigations on high-volume fly ash shotcrete were very promising. Based upon the results of CANMET investigations, Transport Canada used the above type shotcrete for covering several small sections of the outcrops at Halifax airport on an experimental basis. The initial results of this trial are promising with concrete showing almost no cracking after one winter of exposure. The investigation on the fluidized bed combustion waste was less successful with concrete made with the above waste showing excessive expansion. The work on this job was discontinued.

The IDRC/CANMET project on blast-furnace slags is continuing. A presentation on this project was made at a seminar organized by IDRC in Toronto in March 1990.

CANMET was the principal sponsor of the 3rd International Conference on Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete, which was held in Trondheim, Norway, June 1989. Also, the Third International Conference on Superplasticizers in Concrete was sponsored by CANMET and was held in Ottawa, in October 1989.

Future Directions:

Future initiatives will consist of developing technology to activate suplementary cementing materials with or without the use of portland cement. Continued emphasis will be placed on the development of a data bank in long term durability of concrete.

Outputs:

Contracts

- Joint research project CANMET, Ottawa/L.E. Shaw, Halifax, "Utilization of waste from fluidized bed combustion operations as a cementitious material". S.A. - E. Douglas.

- Joint research project CANMET/NRC, Institute for Research in Construction, "Alkali activation of blast-furnace slag". S.A. - E. Douglas.

- Reqn. 7-9146, "Long-term strength development of high-strength field concrete containing silica fume and other supplementary cementing material"; Trow Ltd. S.A. - G.G. Carette.

- Reqn. 8-9064, "Creep studies of high-volume fly ash concrete"; University of Calgary. S.A. - G.G. Carette.

- Reqn. 8-9071, "Preparation and evaluation of composite material made using circulating fluidized bed combustion high-lime waste by-product and preparation plant coarse refuse"; Cape Breton Development Corp. S.A. - E. Douglas.

- Reqn. 8-9194, "Fatigue resistance of lightweight concrete"; University of New Brunswick. S.A. - G.G. Carette.

- Reqn. 9-9099, "Creep studies on high-volume fly ash concrete - a continuing study"; University of Calgary. S.A. - G.G. Carette.

- Reqn. 9-9100, "Optimization of high-volume fly ash concrete mixtures"; W.S. Langley and Associates. S.A. - G.G. Carette.

- Reqn. 9-9103, "Study of activation of blast furnace slags and high volume fly ash systems"; Handy Chemicals Ltd. S.A. - V.M. Malhotra.

- Reqn. 9-9120, "Comparative evaluation of a Canadian lightweight aggregate with those from the U.S.A. and Germany"; University of New Brunswick. S.A. - G.G. Carette.

- Reqn. 9-9182, "Microstructure of alkali activated ground granulated blast-furnace slag in pastes and concrete"; University of Sherbrooke. S.A. - E. Douglas.

- Reqn. 9-9224, "Durability to freezing and thawing cycling of non-air entrained high-strength silica fume concrete"; W.S. Langley & Associates. S.A. - V. Sivasundaram.

- Reqn. 9-9226, "Creep studies on ultra high-strength portland cement and fly ash/silica fume concrete"; W.S. Langley & Associates. S.A. - V. Sivasundaram.

Publications

- Berry, E.E., Hemming, R.T., Langley, W.S. and Carette, G.G., "Beneficiated fly ash: hydration, microstructure and strength development in portland cement systems"; ACI SP 114; pp 241-273; 1989.

- Bilodeau, A. and Carette, G.G., "Resistance of condensed silica fume concrete to the combined action of freezing and thawing cycling and deicing salts"; ACI SP 114; pp 945-970; 1989.

- Langley, W.S., Carette, G.G. and Malhotra, V.M., "Structural concrete incorporating high-volumes of ASTM Class F fly ash"; ACI Materials Journal; Vol. 86, No. 5; 1989.

- Malhotra, V.M., "Superplasticizers: a global review with emphasis on durability and innovative concrete"; ACI SP 119; pp 1-18; 1989.

- Malhotra, V.M. and Painter, K.E., "Early-age strength properties and freezing and thawing resistance of concrete incorporating high-volumes of ASTM Class F fly ash"; International Journal of Cement Composites and Lightweight Concrete 11:1:37-46; 1989.

- Plante, P. and Bilodeau, A., "Rapid chloride ion permeability test: data on concretes incorporating supplementary cementing materials"; ACI SP 114; pp 625-644; 1989.

- Sivasundaram, V., Carette, G.G. and Malhotra, V.M., "Properties of concrete incorporating low quantity of cement and high-volume of low calcium fly ash"; ACI SP 114; pp 45-72; 1989.

Reports

- Alasali, M.M. and Malhotra, V.M., "Role of high-volume fly ash concrete in controlling expansion due to alkali-aggregate reaction"; Division Report MSL 89-61 (OP&J) Draft.

- Berry, E.E., Hemmings, R.T., Langley, W.S. and Carette, G.G., "Beneficiated fly ash: hydration, microstructure and strength development in portland cement systems"; Division Report MSL 88-79 (OP&J).

- Bilodeau, A., Carette, G.G. and Malhotra, V.M., "Mechanical properties of non-air entrained high-strength concrete incorporating supplementary cementing material"; Division Report MSL 89-129 (J).

- Bilodeau, A. and Carette, G.G., "Resistance of condensed silica fume concrete to the combined action of freezing and thawing cycling and deicing salts"; Division Report MSL 88-66 (OP&J).

- Bremner, T., Carette, G.G. and Malhotra, V.M., "Role of supplementary cementing material in concrete for marine environment"; Division Report MSL 89-52 (OP&J).

- Carette, G.G., Malhotra, V.M. and Aitcin, P.C., "Preliminary data on long-term strength development of condensed silica fume concrete"; Division Report MSL 89-9 (OP).

- Douglas, E., Bilodeau, A. and Malhotra, V.M., "A preliminary investigation on superplasticized high-volume slag concrete"; Division Report MSL 89-136 (IR).

- Douglas, E., Bilodeau, A., Brandstetr, J. and Malhotra, V.M., "Alkali-activated ground granulated blast-furnace slag concrete: preliminary investigation"; Division Report MSL 90-14 (J).

- Douglas, E., Bilodeau, A., Malhotra, V.M. and Brandstetr, J., "Alkali activated ground granulated blast-furnace slag concrete: preliminary investigation"; Division Report MSL 89-135 (J).

- Langley, W.S., Carette, G.G. and Malhotra, V.M., "Strength development and temperature rise in large concrete blocks containing high volumes of low calcium fly ash"; Division Report MSL 89-62 (OP&J).

- Malhotra, V.M., Carette, G.G., Bilodeau, A. and Dibble, D., "Fibre-reinforced high-volume fly ash shotcrete for controlling aggressive leachates from exposed rock surfaces and mine tailings"; Division Report MSL 89-70 (OP).

- Malhotra, V.M., "Quality control as a marketing tool for ready-mixed concrete"; Division Report MSL 89-93 (OP).

- Malhotra, V.M., "Mechanical properties of high-strength semi-lightweight concrete incorporating fly ash and silica fume"; Division Report MSL 89-82 (OP&J).

- Malhotra, V.M., "Superplasticizers: a global review with emphasis on durability and innovative concretes"; Division Report MSL 89-19 (OP&J) Draft.

- Malhotra, V.M., "Laboratory and field evaluation of freezing and thawing tests"; Division Report MSL 89-2 (OP&J) Draft.

- Plante, P. and Bilodeau, A., "Rapid chloride ion permeability test: data on concretes incorporating supplementary cementing materials"; Division Report MSL 88-44 (OP&J).

- Read, P., Carette, G.G. and Malhotra, V.M., "Strength development characteristics of high-strength concrete incorporating supplementary cementing materials"; Division Report MSL 89-89 (OP&J) Draft.

- Sivasundaram, V., Bilodeau, A. and Malhotra, V.M., "Mechanical properties of non-air entrained high-strength concrete incorporating silica fume with and without blast-furnace slag"; Division Report MSL 89-101 (J).

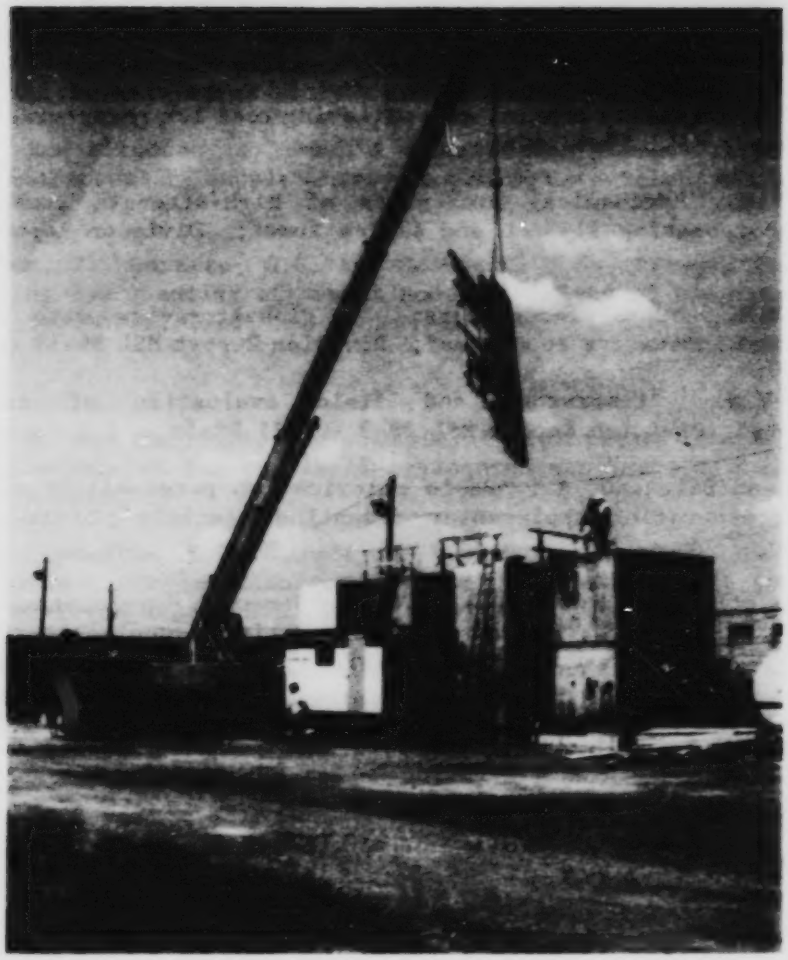

Fig. 6. Field testing of high-volume fly ash concrete developed at CANMET.

Project 30.37.02: Development of Concrete Technology for Offshore Structures
Project leader : V.M. Malhotra

Objective:

To develop engineering data on high-strength, low permeability, and high impact resistance concrete and grouts for offshore structures; to develop concrete permeability and ice abrasion resistance and NDT monitoring inspection tests. This program is supported through the federal energy R&D program under the Panel on Energy R&D.

Oil exploration and production activities in the offshore arctic environment are expected to increase in the near future. It is anticipated that many of the offshore structures will be constructed of concrete. At present there are many unknown factors related to the performance of concrete structures in the arctic environment. The extreme cold adversely influences the properties of concrete. The ice creates additional problems of abrasion and impact. It is therefore essential that studies be performed to develop concretes which will be durable in the arctic environment. Such concrete should have high strength, low permeability and low unit weight. Also, testing methodology should be developed to determine abrasion resistance and permeability of these special concretes.

Highlights and Achievements:

The first monitoring of the large reinforced concrete test prisms which were installed at Treat Island in August 1988, were performed and a brief report has been prepared by the contractor. The monitoring of the test specimens will be continued at yearly intervals for the next ten years. The eleventh yearly inspection of the previously installed test prisms at Treat Island was performed and photographs taken. New visual displays are being prepared for presentations at future CANMET/ACI sponsored conferences and seminars.

Eight large test cylinders with compressive strength of 15, 20, 25 and 35 MPa have been fabricated by Laboratoire de Béton Ltée., Montreal, for determining the combined action of ice abrasion and impact. The testing will be performed by Fleet Engineering Ltd., Kanata. Mobil Oil Research Ltd., Dallas will contribute $36K towards the testing of these specimens. A joint paper will be published on the subject once the testing has been completed.

A visit was made to Nanisivik, Baffin Island to inspect 12 high-strength concrete panels (150 x 330 x 3660 mm in size) which had been installed in 1987 on the side of an existing dock. A team of researchers from the University of Sherbrooke, Quebec accompanied CANMET personnel. The above University had fabricated the panels under a CANMET contract, and was invited to visit Nanisivik to take concrete cores from the panels for micro-structural analysis. A report has been prepared on the test results and after three years exposure, no changes of any practical significance are evident. A technical note will be prepared for publication. The next visit to Nanisivik is planned for 1991.

Investigations have commenced to determine the performance of lightweight concrete incorporating high volumes of fly ash using three different types of lightweight aggregates from sources in Canada, U.S.A. and Germany. This is a joint industry/CANMET investigation, and is being performed by the University of New Brunswick.

A report is under preparation for a study dealing with a round robin program on air-void analysis of hardened concrete.

Nolan Davis Ltd., St. John's, Newfoundland completed, under contract, a study on the utilization of Newfoundland aggregates to produce high-strength concrete for offshore structures. The studies indicated that satisfactory strengths can be achieved using the aggregates tested. Little progress was made to develop

permeability data on 50 mm thick concrete specimens due to the Contractor having staffing problems. The work will be resumed in the near future.

Future Directions:

Future initiatives in this project will focus on the continued monitoring of the test specimens at the outdoor exposure sites of Treat Island and Nanisivik. Also, attempts will be made to develop prototype automatic accelerated freezing and thawing equipment.

Outputs:

Contracts

- Reqn. 6-9174, "Utilization of Newfoundland aggregates to produce high-strength concrete for offshore structures - Phase I"; Nolan Davis Ltd. S.A. - A. Bilodeau.

- Reqn. 8-9095, "Monitoring of Nanisivik concrete panels"; Université de Sherbrooke. S.A. - G.G. Carette.

- Reqn. 8-9167, "Development of permeability data on 50 mm thick concrete specimens"; Laboratoire de Béton Ltée. S.A. - G.G. Carette.

- Reqn. 8-9244, "Monitoring of concrete test specimens at Treat Island, ME, 1989"; Univeristy of New Brunswick. S.A. - G.G. Carette.

- Reqn. 8-9250, "Differents critères nécessaire à la réalisation de systèmes de protection cathodique pour les structures de béton armé affectées par la corrosion électrochimique"; Laboratoire de Béton Ltée. S.A. - G.G. Carette.

- Reqn. 9-9171 "Compressive strength test procedures for testing high strength concretes"; Trow Inc. S.A. - G.G. Carette.

Fig. 7. Testing of concrete in the Arctic environment of Nanisivik, Baffin Island.

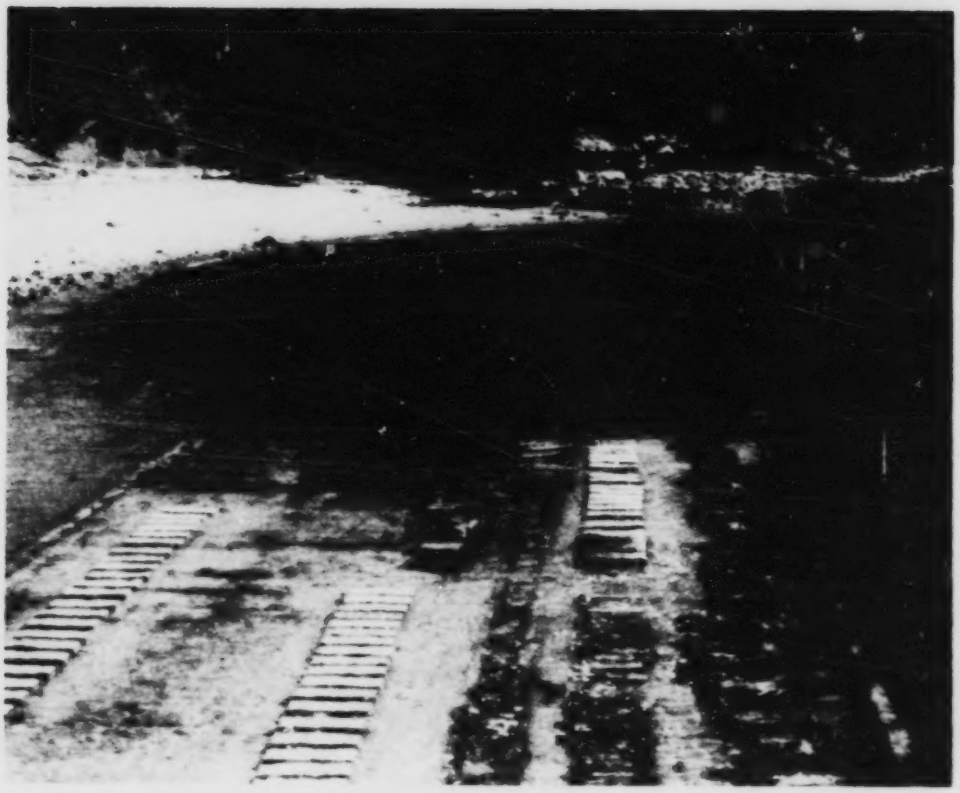

Fig. 8. Testing of concrete under sea waters at the outdoor exposure site of Treat Island, ME.

Project 30.37.03: Development of National and International Standards for Concrete
Project leader : G.G. Carette

Objective:

To provide technical expertise and information for Canadian and international standards writing organizations concerned with aggregates and concrete, by performing development work on in-situ tests, NDT methods and other tests, by coordinating the CSA Sample Comparative Cement testing program, by organizing conferences on the use of NDT and new concrete materials and their durability, and by participating in committees of the CSA, ACI, ASTM, ISO, etc.

The Canadian cement and concrete industry is a multi-million dollar mineral-based industry and the efficient use of these materials in the field demands that there should be uniform product quality and testing standards across Canada. To achieve this, it is essential that any new information developed in the area of cementitious material be readily made available to the concerned industry and be incorporated in the national and international standards. Aggregates, cement and concrete testing and standards contribute much to ensuring that concrete will perform as specified in construction projects, thus protecting public interest and safety.

Highlights and Achievements:

a) Joint comparative CSA cement sample program

At the request of the Committee on Hydraulic Cement of CSA and the Canadian cement industry, a joint project was initiated at the end of 1978 between Canadian cement testing laboratories and CANMET to assess existing cement specifications and testing methods in Canada. CANMET is coordinating the program and is in charge of the overall organization, including the preparation and distribution of test samples, and the compilation, analysis and publication of test data.

Also, at the request of the above committee, CANMET is coordinating a National Cement Monitor sample program for the purpose of providing the industry with a means of verifying their cement strength testing procedures. The monitor sample became available in the Fall of 1988 and is being distributed through the Canadian Certified Reference Materials Project of CANMET. To date, a total of 114 unit samples have been distributed to cement testing laboratories across Canada.

b) Conferences, workshops and seminars

CANMET, in association with the American Concrete Institute, U.S.A., sponsored the 2nd International Conference on Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete in June 1989, in Trondheim, Norway. The five-day conference was highly successful with more than 400 delegates from 30 different countries attending. The program covered a total of 150 technical presentations which were published in the conference proceedings, and included a special CANMET session on high-volume fly ash concrete. It also featured technical visits to national cement and concrete research organizations such as SINTEF and a field trip to the offshore platform construction sites at Stavanger.

CANMET also sponsored the 3rd International Conference on Superplasticizers and Other Chemical Admixtures in Concrete in October 1989 in Ottawa. The three-day conference was again most successful, attracting more than 200 delegates from 21 different countries. A total of 45 technical papers were presented and published in the conference proceedings.

Future Directions:

The CSA round-robin cement testing program will be continued. A second national

monitor cement sample will be prepared and made available to the industry through CANMET. Developmental work with respect to NDT and various durability test procedures and equipment will be pursued. Transfer of technology will be continued through the organization of the 2nd International Conference on Durability of Concrete and the 3rd International Conference on Fly Ash, Silica Fume and Slag in Concrete, both under the co-sponsorship of CANMET and the American Concrete Institute.

Outputs:

Report

- Carette, G.G., "Current CANMET research on concrete"; Division Report MSL 89-65 (OP&J).

Project 30.37.04: Alkali Aggregate Reactivity
Project leader : V.M. Malhotra

Objective:

To develop petrographical and mineralogical data on rock types which may be potentially reactive with alkalies from portland cement; to develop engineering data on mineral admixtures to control the above expansive reactions and to evaluate various accelerated tests to predict potential expansion of reactive aggregates in concrete.

For long-term durability, the aggregates used in concrete must be physically durable and chemically inert. However, in recent years, a large number of cases have been documented where the aggregates have reacted with alkalies from cement and/or deicing salts and the expansive reactions have resulted in very serious distress to many concrete structures. These include hydro-electric dams, bridges, buildings and concrete railroad ties. The structural damage has been estimated to be in the millions of dollars.

Therefore, it is essential that research be undertaken to identify potentially reactive rock-types, and means be found to control this reaction by the use of supplementary cementing materials. As these reactions are slow and take many years to manifest themselves, it is imperative that accelerated testing methodologies be developed to predict potentially reactive aggregates.

Highlights and Achievements:

Investigations being performed by various contractors in New Brunswick, Nova Scotia and Newfoundland under their respective MDAs are either complete or nearing completion. The contractors' reports are being reviewed and several reports are planned for publication. An international workshop "Alkali-aggregate Reactions in Concrete: Occurrences, Testing and Control" is being sponsored in Halifax in May 1990 and results of the above investigations will be presented.

A contract has been negotiated with École Polytechnique to determine stresses due to alkali-aggregate reactions in small structural members.

A Post-Doctoral Fellow completed his evaluation of the various accelerated test methods for determining the potential alkali-aggregate reactions in concrete. The most promising accelerated method was the one in which test prisms are cured at 80°C. Investigations are being planned to determine if curing at 60°C will yield similar results. A report has been prepared for presentation at the Halifax workshop. Also, investigations were completed on the role of a high-volume fly ash system to control alkali-aggregate reactions, and the test results show that this system is excellent in reducing the expansion due to the above reactions.

Future Directions:

In this project, future initiatives will include the continued evaluation of accelerated test methods and the development of data on the role of supplementary cementing meterials in controlling the alkali-aggregate reactions. Also, the MDA reports dealing with AAR in the maritimes will be summarized for publication as technical papers.

Outputs:

Contracts

- Reqn. 2-9200, "Utilization of Canadian pozzolanic materials in reducing the effects of alkali-aggregate reactivity"; Lafarge Canada Ltd.; S.A. - J.A. Soles and V.M. Malhotra.

- Reqn. 4-9236, "Study of the alkali-reactivity of the potential concrete aggregates of N.B."; ADI Ltd.; S.A. - J.A. Soles.

- Reqn. 5-9255, "Study of the alkali-reactivity of the potential concrete aggregates of Newfoundland"; Golder and Associates. S.A. - J.A. Soles.

- Reqn. 6-9157, "Study of the alkali-aggregate reactivity of the potential concrete aggregates of Nova Scotia"; Jacques Whitford and Associates Ltd. S.A. - J.A. Soles.

Publication

- "CANMET investigations of supplementary cementing materials for reducing alkali-aggregate reactions. Part 1: Granulated/pelletized blast-furnace slags"; ACI SP 114; pp 1637-1656; 1989, (ed. V.M. Malhotra).

Project 30.37.05: Mine Backfill
Project leader : E. Douglas

Objective:

To investigate the utilization of metallurgical and industrial wastes for partial or total replacement of portland cement in cementing mine backfill.

Mining companies have traditionally used portland cement for binding backfill materials, but the need to reduce operating costs has prompted these companies to begin investigations into lower cost alternatives to portland cement.

Ferrous and non-ferrous slags and fly ashes possess hydraulic or pozzolanic properties and their use for total or partial replacement of portland cement in mine backfill in the mining industry represents a significant operating cost reduction while, at the same time, contributing to the solution of environmental problems such as waste accumulation and soil contamination due to leaching.

Highlights and Achievements:

a) Use of ground granulated copper slag in consolidated rockfill

A memorandum of agreement between CANMET and Falconbridge Limited, Kidd Creek Division was signed to carry out a joint research project dealing with the utilization of Kidd Creek granulated copper slag in consolidated rockfill.

The total cost of this work is estimated at $170K over a period of two years, with a total cost to CANMET estimated at $100K.

A comminution study for the reduction of grinding energy cost of the granulated copper slag was carried out. A reduction of approximately 20 kW/h/t can be obtained by roll crushing the material prior to ball milling. Compressive strengths of backfill with binders made up of portland cement-ground granulated copper slag were determined and the effect of various activators was investigated. Addition of a small percentage of anhydrite to the binder considerably improves early and long-term strengths. Feasibility studies are underway.

b) Strength development in ternary blended cements

Strength development in portland cement blast-furnace slag/fly ash systems, with possible applications in mine backfill, was investigated in mortar specimens. A computerized statistical approach was used to find the equation governing strength development of the ternary systems at different ages in order to project the compressive strength values of any ternary blend proportioned within the given boundaries. The accuracy of the projected values was evaluated as 95% or better.

Future Directions:

Studies on the activation of granulated copper slag will be continued and a field test utilizing the activated portland cement-copper slag binder in rockfill will be carried out.

Concrete mixtures will be made of selected ternary binder systems and tested.

Outputs:

Contract

- Reqn. 8-9259, "Comminution study for reduction of grinding energy cost of granulated copper slag"; Grinding Process Development. S.A. - E. Douglas.

Publication

- Douglas, E. and Malhotra, V.M., "Ground granulated blast-furnace slag for cemented mine backfill: production and evaluation"; CIM Bulletin 82:929:27-36; 1989.

Report

- Douglas, E., Malhotra, V.M. and Pouskouleli, G., "Strength development in mortars of portland cement-ground granulated blast-furnace slag-fly ash blends"; Division Report MSL 89-134 (J).

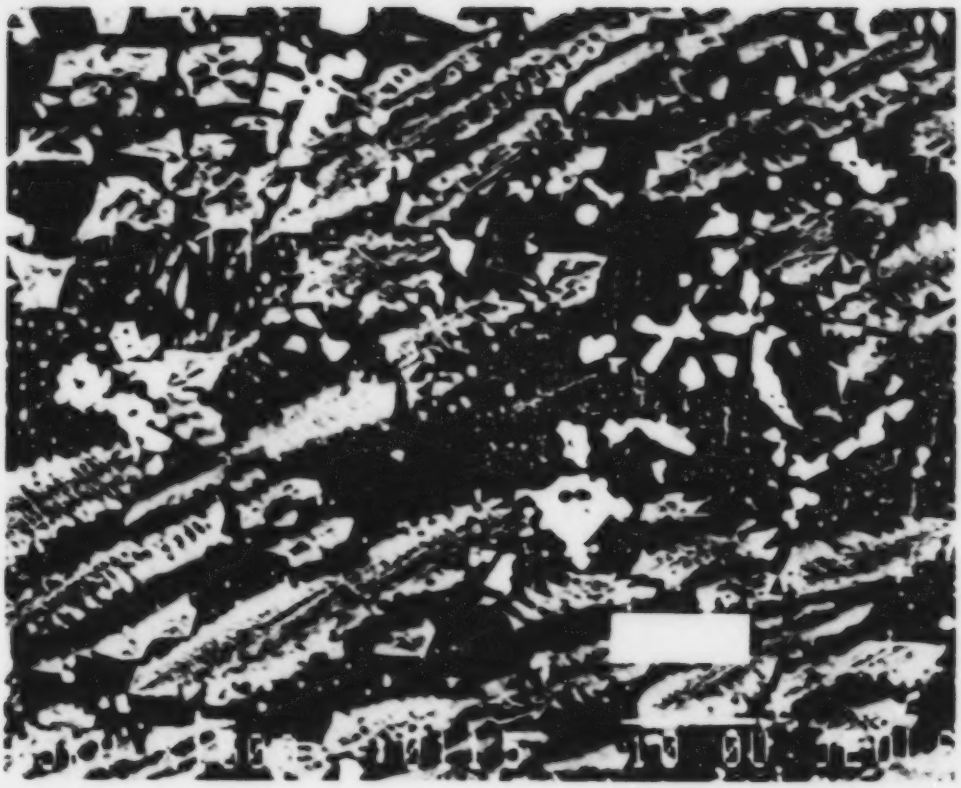

Fig. 9. Microstructure of air-cooled copper slag.

Biotechnology

Project 30.46.01: Biotechnology
Project leader : R.G.L. McCready

Objective:

To identify, quantify, test and apply biological phenomena to improve mineral processes for the recovery of metal values, to enhance recovery of fossil fuels and to reduce the environmental impact of industrial operations in these fields to acceptable levels.

Highlights and Achievements:

a) Bacterial leaching of sulphide ores

The objective is to develop an economically viable biohydrometallurgical process to extract and recover secondary metal values from sulphide ores, specifically those portions of mineral deposits which are left underground for mine support or which are below cut-off grade for conventional milling.

Typically 30% of mineral deposits are left untouched in most mining operations. Treatment of such residual resources by bacterial leaching would enable complete utilization of ore reserves.

Projects in this area include commercial underground leaching of uranium and a large pilot-plant study on the leaching of copper and zinc from a complex sulphide ore.

b) Preferential and sequential leaching of a complex sulphide ore

The objective is to determine the rate and sequence of bioleaching of a complex sulphide ore with a view to obtaining a better understanding of the mechanism of oxidation of metal sulphides by Thiobacillus ferrooxidans and Thiobacillus thiooxidans.

c) Biosorption of uranium

The objective is to assess various biomass and develop an economic biological process for the recovery of uranium from dilute solutions.

CANMET is currently conducting a pilot-plant study on the biosorption of uranium from dilute bioleach pregnant liquors using immobilized Rhizopus arrhizus in a column system analogous to an ion exchange system. On stripping the uranium from the column, peak concentrations as high as 14 g/L have been obtained with an overall concentration of uranium by a factor of 40-fold.

d) Metal recovery from dilute solution

CANMET has developed a biological, reductive process to recover selenite from smelter effluents as elemental selenium. With this technology an environmental problem is resolved while simultaneously producing a secondary marketable product.

e) Biological treatment of industrial effluents

The objective is to develop biological processes to protect the environment from potentially toxic compounds resulting from the processing of minerals or fossil fuels.

i) Biodegradation of organics in tailing recycle water

Many mining operations have a limited supply of water and thus must recycle their process water to maintain operations. However, often when water is recycled, the presence of contaminants results in increased reagent consumption or reduced recoveries of values. CANMET is working cooperatively with a mining company and McGill University to develop a biological process to remove the residual mill reagents from tailings effluents to allow their recycle back into the flotation circuit.

ii) Biodegradation of deicing fluids and urea

Each major airport in Canada uses greater than 1,000,000 litres of ethylene glycol each winter for deicing aircraft. As ethylene glycol has a high biological oxygen demand and is biologically toxic in high concentrations it must be removed from the airport run-off prior to release of the water into the environment. CANMET, in cooperation with Transport Canada, has developed a rotating biological contactor-based process to degrade ethylene glycol and urea.

f) Biological treatment of acid mine drainage

Acidic mine drainage is the most severe environmental problem facing the mining industry today. There is a concerted research effort to develop a passive, self-sustaining treatment system which will be suitable for the eventual mine close-out. Such a system must be economic, require minimal maintenance and be effective for an extended period of time.

i) Biological removal of As and Hg

Abandoned gold mill tailings, in which the gold was recovered by mercury amalgamation, contain high concentrations of both mercury and arsenic. During the weathering process these elements are leached from the tailings into the environment. CANMET is supporting the assessment of aquatic macrophytes as a biological means of immobilizing and mineralizing these elements within the tailings or in the sediments of adjacent water courses.

ii) Ecological engineering for AMD treatment

Over the past five years CANMET has supported, under contract, work to develop an acid tolerant ecosystem which may effectively raise the pH, immobilize and mineralize the soluble metal ions, and provide a long term biological treatment system for mine close-outs. The results to date have been very promising and a large field test is being conducted in Sudbury this year.

iii) Microbial sulphuretum to treat acid mine drainage

CANMET is conducting a laboratory investigation to optimize the development of a bacterial sulphuretum to mitigate the pH, immobilize and mineralize soluble metal ions, and protect the environment from the potential damage associated with acid mine drainage. This system is specifically designed

to treat small acidic drainage streams in a cost effective manner. The laboratory study has been so successful that a full-scale field study has been implemented in cooperation with Transport Canada.

g) Biotechnology for fossil fuels

CANMET is initiating a program on the application of biotechnology for fossil fuel processing and treatment of industrial wastes or effluents for environmental protection.

i) Biofouling and corrosion of process streams

During secondary oil recovery water is continually injected into the oil reservoir in the hope of driving the residual oil from the formation into the recovery well. During the continuous recycle of the water, it becomes contaminated with organisms and if these organisms are not controlled with biocide treatment, extensive biofouling and internal corrosion of the process stream may occur. Further, many of the commonly used biocides have been banned for use and the industry requires a means of testing registered biocides to control their contamination problems. CANMET and Nova Husky Research Corp. currently have a cost-shared program to assess various biocides and to determine the mechanism of biofilm formation and the development of internal corrosion.

ii) Hydrogenase test kit to identify sulphate reducing bacteria

Sulphate reducing bacteria are known to be the predominant species associated with corrosion of metals. Fossil fuel storage facilities and secondary recovery facilities are very prone to biocorrosion as these sites rapidly become anaerobic, thereby promoting the growth of sulphate reducing bacteria. Researchers at the University of Calgary recently developed an enzyme assay kit for the detection of sulphate reducing bacteria (SRB's) in soils or water samples. The current contract is to assess the potential of this enzyme assay kit as a means of determining the presence of SRB's in oil storage or processing facilities.

iii) Microbial plugging of porous zones in reservoirs

Often during the drilling of production wells, the companies will strike a fractured or porous formation resulting in the loss of large volumes of drilling fluids or muds. In order to maintain the lubrication of the drill bit and to remove rock chips etc. from the drilling face, this porous or fractured zone must be plugged to maintain the continuous flushing of the drill bit with lubricating drilling muds. CANMET is supporting research to assess the feasibility of using exopolymer producing bacteria as a means of sealing off this porous zone.

h) Biotechnology networking

The objective is to maintain and expand, on a continuing basis, a network to improve the interaction and communication between the research community and

Canadian industry, in order to improve the availability and accessibility of relevant information on biotechnology.

Personnel from CANMET:

1. Prepared and published four BIOMINET Newsletters to make members aware of current research projects and developments in the application of biotechnology in the fossil fuel and mineral industries.

2. Organized and presented the BIOMINET Annual Meeting at the Institute Armand Frappier, in both official languages.

3. Published the BIOMINET Proceedings from the 1988 Annual Meeting in Calgary (CANMET SP 88-23).

4. Organized and presented a session on "Biocorrosion" at the CANMET Pipeline Seminar in Calgary on October 30-31, 1989.

5. Co-organized and co-chaired the International Symposium on Biohydrometallurgy at Jackson Hole, Wyoming, August 13-18, 1989.

6. Edited and published the Proceedings of the International Symposium on Biohydrometallurgy.

7. Acted as a member of the Technical Committee on Acid Mine Drainage at the Halifax International Airport.

8. Were invited to present overviews of the biotechnology activities in the mineral and fossil fuel sectors within Canada at the International Symposium on Biotechnology for Energy, Faisalabad, Pakistan, December 12-18, 1989.

9. Were invited to present a paper at the Canadian Water Conservation Association Annual Meeting in Calgary.

10. Were invited to present the BIOMINET Workshop entitled "Basic Microbiology for the Mineral Industry" at the Pacific Rim Congress in Gold Coast, Australia.

Future Directions:

The Biotechnology program will continue to address environmental issues in the future particularly in waste management, removal of toxic metal ions from solution and biodegradation of industrial wastes in both the mineral and fossil fuels sectors.

Outputs:

Contracts

- Manitoba MDA Agreement: Hudson Bay Mining and Smelting, University of Manitoba and Ortech International conducted a large-scale column leaching study on

bacterial leaching of a complex sulphide ore and the recovery of copper and zinc by solvent extraction.

- Reqn. 9-0006, "Internal biocorrosion of steel pipes"; Nova-Husky Research Corp. S.A. - R.G.L. McCready.

- Reqn. 8-9082, "Loss of uranium adsorption capacity of recycle"; McMaster University. S.A. - R.G.L. McCready.

- Reqn. 9-9104, "Acid generation and inorganic precipitate formation in mine tailings"; Boojum Research Ltd. S.A. - R.G.L. McCready.

- Reqn. 9-9015, "Optimization of the sol-gel immobilization of biomass"; Ortech International. S.A.- R.G.L. McCready.

- Requ. 9-9019, "Competing ions for the bioadsorption of uranium"; McMaster University. S.A. - R.G.L. McCready.

- Reqn. 9-9128, "Study on the plugging of "thief zones" using bacteria and foams"; Microbios Ltd. S.A. - R.G.L. McCready.

- Reqn. 9-9129, "Study on the use of the hydrogenase test to detect H_2S production in oil storage and processing facilities"; Microbios Ltd. S.A. - R.G.L. McCready.

- Reqn. 9-9140, "Preparation of a VHS documentary on ecological engineering and the chara process"; Boojum Research Ltd. S.A. - R.G.L. McCready.

- Reqn. 9-9141, "Morphological/anatomical investigation of cattail transplants and bog vegetation"; Boojum Research Ltd. S.A. - R.G.L. McCready.

- Reqn. 8-9156, "Consultant services on the biosorption pilot-plant"; Tsezos Consulting Engineer. S.A. - R.G.L. McCready.

- Reqn. 8-9260, "Heavy metal removal from gold mines using indigenous aquatic macrophytes"; P. Lane and Associates. S.A. - R.G.L. McCready.

- Reqn. 8-9264, "Biological and microbial treatment of base metal acid mine drainage"; Boojum Research Ltd. S.A. - R.G.L. McCready.

Patents

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- McCready, R.G.L., Gould, W.D., Chalykoff, C. and Worgan, J., "Biodegradation of alkylene glycols using selected bacteria"; Can. Patent Appl. No. 613,421; September 27, 1989.

- McCready, R.G.L., Gould, W.D. and Salley, J., "Biorecovery of selenium"; Can. Patent Appl. No. 580,256; December 14, 1989.

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- Béchard, G., Rajan, S., Salley, J. and McCready, R.G.L., "Neutralization of acid mine drainage using microbial processes"; BIOMINET Proc.; CANMET SP 89-9; pp 61-76; 1989.

- Cuif, J.P., Salley, J., McCready, R.G.L. and Tsezos, M., "Selective concentration of uranium from bioleached solutions using immobilized biomass in a continuous pilot-plant"; BIOMINET Proc.; CANMET SP 89-9; pp 1-25; 1989.

- Gibling, M.R., Zentilli, M. and McCready, R.G.L., "Sulphur-rich coal in the Pennsylvanian of Atlantic Canada: geologic and isotopic evidence for bedrock evaporites as the sulphur source", Intl. J. Coal Geol. 11:81-104; 1989.

- Gould, W.D., Chalykoff, C., McCready, R.G.L., Salley, J. and Worgan, J. "Microbial degradation of ethylene glycol using a rotating biological contactor"; BIOMINET Proc.; CANMET SP 89-9; pp 45-59; 1989.

- Gould, W. D., Krouse, H.R., McCready, R.G.L. and Rajan, S., "Stable isotope composition of sulphate produced during bacterial oxidation of various mineral sulphides"; Biohydrometallurgy 1989, eds. J. Salley, R.G.L. McCready and P.L. Wichlacz; CANMET SP 89-10; pp 81-92; 1990.

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- Tackaberry, P., Lakshmanan, V.I. and McCready, R.G.L., "The development of an economical growth medium for the production of uranium adsorbing fungi"; BIOMINET Proc.; CANMET SP 89-9; pp 109-126;1989.

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- Tsezos, M., McCready, R.G.L., Salley, J., Cuif, J.P., "The use of immobilized biomass for the continuous recovery of uranium from Elliot Lake ore. First pilot plant results"; Biohydrometallurgy 1989, eds. J. Salley, R.G.L. McCready and P.L. Wichlacz; CANMET SP 89-10; pp 279-287; 1990.

Reports

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- Salley, J., McCready, R.G.L. and Cuif, J.P., "Comparison of uranium biosorption between Scytalidium acidophilum and Rhizopus arrhizus"; Division Report MSL 89-29(J) Draft.

- McCready, R.G.L., "Biotechnological processes in the Canadian mining industry; Division Report MSL 89-99 (OP&J) Draft.

- McCready, R.G. L., "Canadian biotechnological developments in fossil fuels"; Division Report MSL 89-100 (OP&J) Draft.

- McCready, R.G.L., Gould, W.D., Rajan, S., Beaulne, M. and Mainwaring, P., "Bacterial and chemical leaching of complex sulphide ores"; Division Report MSL 89-119 (OP&J) Draft.

- McCready, R.G.L., Salley, J. and Gould, W.D., "Biorecovery of selenium from smelter effluents"; Division Report MSL 89-113 (OP&J) Draft.

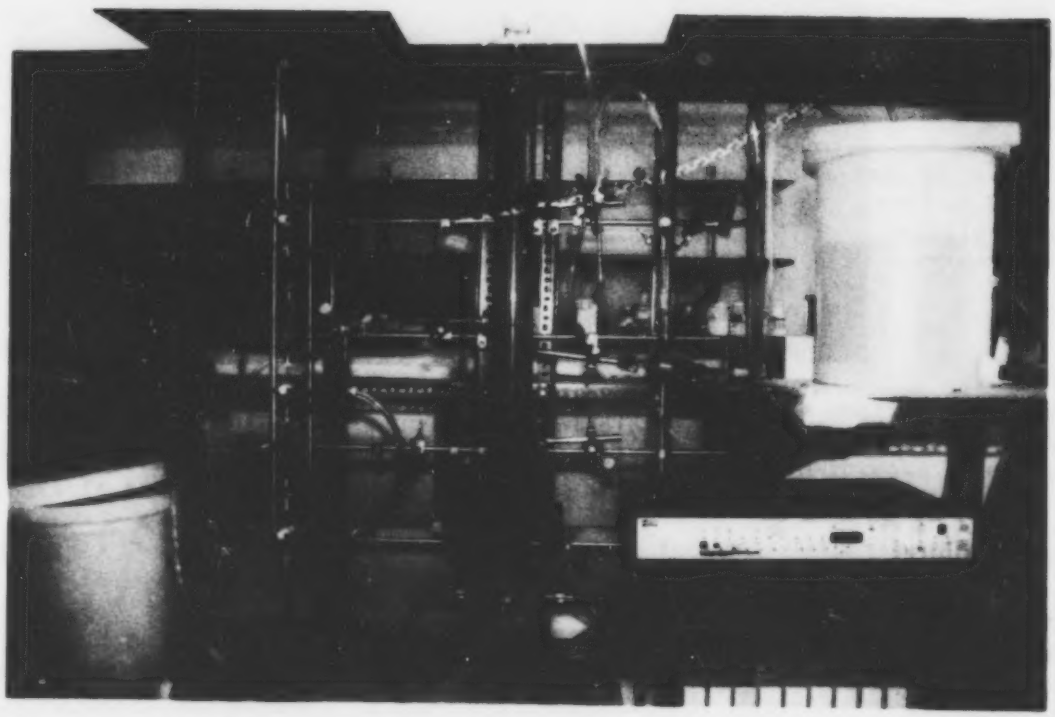

Fig. 10. Biosorption of uranium.

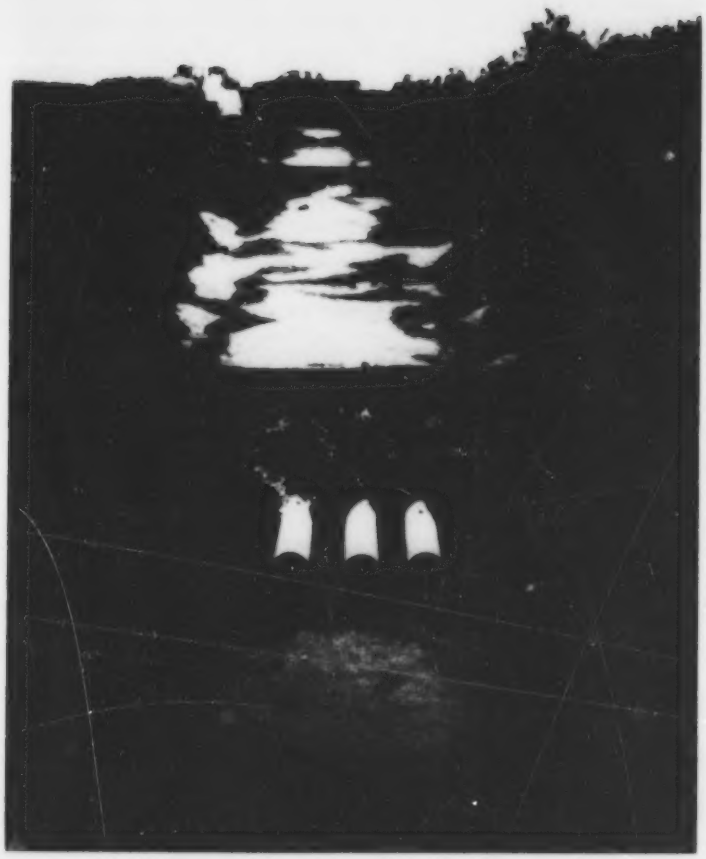

Fig. 11. Biological treatment of acid mine drainage.

Pyrometallurgy

Project 30.47.01: Plasma
Project leader : J.M. Skeaff

Objective:

The objective of this project is to investigate and develop applications of plasma technology in the fields of energy utilization and pyrometallurgy as a

means of increasing energy use efficiencies and of substituting electricity for fossil fuels.

Plasma technology has the potential in many instances for the efficient substitution of electrical energy for fossil fuels utilization as well as for completely new applications. It is also evident that plasma technology has developed to the state where applications on an industrial scale are being seriously considered, are planned or are a reality. However, Canada, although possessing more than adequate supplies of relatively inexpensive electricity, lags behind in the development of industrial plasma technology. To assist in the development of this technology, CANMET has undertaken to investigate potential industrial applications of plasma technology.

Highlights and Achievements:

Advances have recently been made in the application of thermal plasma technology in the development of new high temperature ceramic materials. These materials, which include various oxides, carbides, silicates and others, combine desirable properties such as heat, wear and corrosion resistance. Silicon carbide is considered to be one of the most promising advanced ceramic materials for potential applications in heat engines and industrial parts subject to wear. Thermal plasma has been used under contract at the University of Sherbrooke to provide the ultra high temperatures necessary for the reaction between silicon and methane in the vapour phase. The reaction produced ultra-fine silicon carbide, mainly β-SiC, used for advanced ceramic applications in which superior thermal, mechanical, electrical or chemical characteristics are required. The results of the study were presented at a seminar at CANMET. Further work will focus on the sinterability of the submicron SiC.

An investigation into the production and physical properties of titanium silicides and titanium-iron-silicides is also underway under contract at Queen's University. Silicides were produced by both carbothermic and metallothermic reactions. The oxidation behaviour of the various silicides are very dependent on alloying and impurity concentrations.

Future Directions:

Consideration is being given to incorporation of plasma as a heating source for the calcination of strontium carbonate. Samples of the material are being subjected to laboratory scale trials at the University of Sherbrooke. Research partnership between industry and government will be sought.

Outputs:

Contracts

- Reqn. 7-9180, "Plasma synthesis of ultrafine silicon carbide powders"; University of Sherbrooke. S.A. - S.A. Mikhail.

- Reqn. 7-9196, "Plasma production of titanium silicides and titanium-iron-silicides"; Queen's University and University of Toronto. S.A. - C.A. Hamer.

- Reqn. 9-9077, "Plasma-arc based gasification of coal for preheating of reducing gases for a direct reduction process"; Queen's University, co-funded by the Centre for Chemical Process Metallurgy and URIF, Ontario Ministry of Colleges and Universities. S.A. - D.T. Liang.

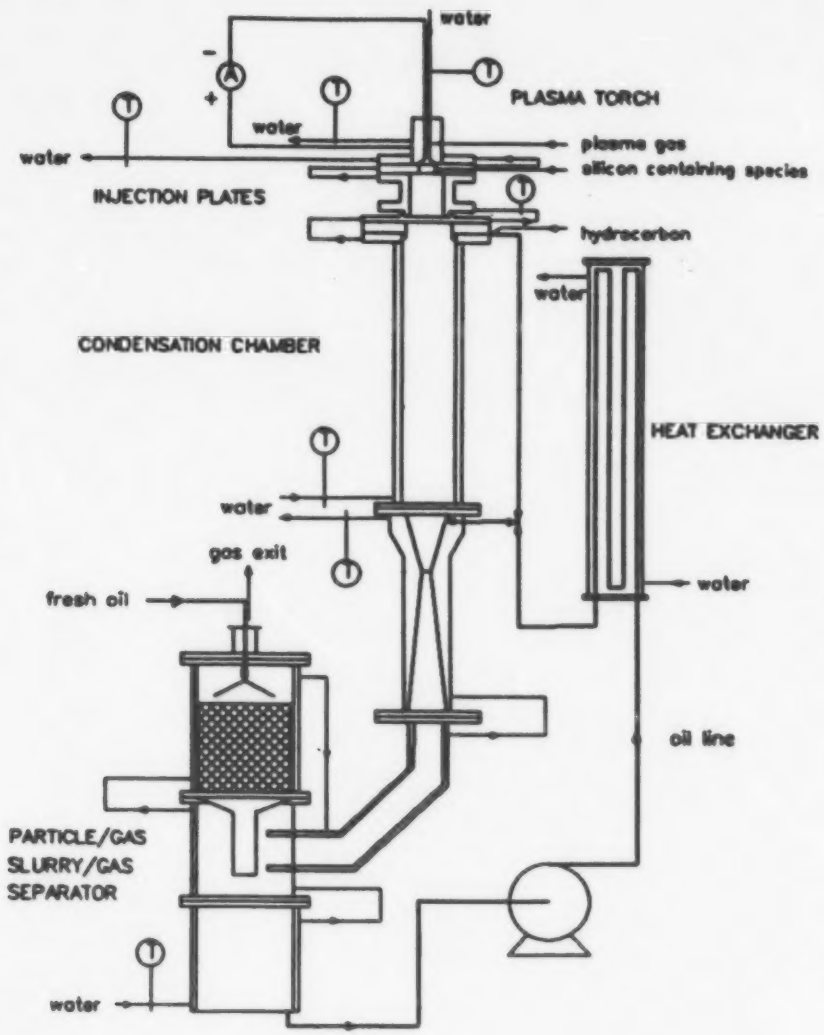

Fig. 12. Schematic diagram of laboratory apparatus for plasma synthesis of ultra-fine silicon carbide powders.

Project 30.47.02: Nonferrous Smelter Technology
Project leader : W.J.S. Craigen

Objective:

Canada's nonferrous smelter industry is a major producer of nonferrous metals and a major emitter of SO_2. CANMET, in cooperation with other federal and provincial government departments and agencies, is assisting the industry in the development and implementation of new and improved technologies for smelter modernization, which will substantially reduce gaseous (SO_2) emissions while increasing the industry's productivity and international competitiveness.

Financial assistance for technology development projects is being obtained from DRIE (IRDP); federal/provincial MDA's; IRAP; NSERC and CANMET/DSS contracts. CANMET is the scientific authority on all government assisted technology development projects with the smelter industry.

Highlights and Achievements:

a) DRIE/IRDP projects

i) Flash converting - INCO Sudbury

A new "flash converting" project has been initiated, with CANMET and DRIE approval, with testwork to be carried out primarily at Port Colborne. The objective of this five-year, $18.5M project is to develop on a demonstration plant scale, a continuous flash converting process for bulk Ni/Cu matte, and thereby facilitate SO_2 capture by eliminating the majority of the present batch converting operations. This technology development project also includes flash converting of MK matte (Cu_2S), and evaluation of gas cleaning and cooling techniques and methods for recycling smelter and converter dusts. The technology developed can be readily integrated with Inco's planned (1994) smelter modernization.

Initial testwork at Port Colborne on the evaluation of gas cooling/cleaning techniques was successfully completed. Transfer of this technology to Sudbury and evaluation on a larger scale is proceeding satisfactorily.

ii) Pyrrhotite (Po) rejection - Falconbridge

The objective of the Po rejection project is to decrease the Po content of the smelter feed by 20% while holding nickel losses to less than 1.5%. Two flowsheets have been tested on a pilot scale at Lakefield. Both employ magnetic and flotation separation circuits. One flowsheet showed a significant improvement over average 1988 mill performance for Po rejection and concentrate grade, while maintaining nickel recovery at essentially the same level. Further testwork on column flotation, new reagents and the use of nitrogen is continuing.

iii) Increased roast - Falconbridge

The increased roast project is designed to maximize the amount of sulphur that can be removed as SO_2 from the roasters, and thereby maximize SO_2 capture by converting this relatively high strength SO_2 gas to sulphuric acid in the acid plant. To accomplish this, modifications to the roaster off-gas and gas cleaning systems have been implemented and successfully tested to handle the increased gas flows. Modifications to increase acid plant capacity have also been initiated. Copper coolers have been installed and successfully tested in the electric furnaces.

An evaporative spray cooler system was selected as the best alternative for cooling the electric furnace off-gases. Work on alternate reductants to coke is continuing and the first run at the Ontario Hydro pilot plant was successfully completed.

iv) Converter slag cleaning - Falconbridge

To reduce the reduction burden on the electric furnace and facilitate the increased roast, a separate process has been developed and implemented to clean converter slag. This patentable process has been successful in improving cobalt recovery by 15% and nickel recovery by about 0.3%. Process development is continuing and includes testwork on solids injection and preliminary studies on the feasibility of producing FeSi from converter slag. The FeSi would be used as a reductant in the converter slag cleaning process.

v) Smelter modernization, phase II - Falconbridge

An IRDP application for demonstration plant testing to determine the techno-economic feasibility of going to very high (85%) degrees of roast and thereby further increasing SO_2 capture, has been submitted by Falconbridge. Although this application has been approved by CANMET and DRIE, Falconbridge has decided to delay implementation. The project is designed to further reduce SO_2 emissions but would provide no significant return on investment to Falconbridge.

b) DRIE/EMR projects

i) HBMS smelter modernization

HBMS has submitted a detailed financial analysis for the planned smelter modernization at Flin Flon to justify their request for government financial assistance. Based on the HBMS submission, CANMET has carried out a techno-economic assessment of the alternatives for smelter modernization and has provided support for the HBMS proposal. The proposal is premised on implementing the zinc pressure leach (ZPL) process for zinc, and retrofitting the copper smelter with a Noranda Reactor and an electric furnace for slag cleaning.

An environmental assessment of the planned HBMS smelter modernization has been carried out by HBMS and verified by CANMET and DRIE. Formal agreement

on the terms for implementing the smelter modernization is awaiting approval by environmental authorities and the Manitoba Government.

c) CANMET/NSERC projects

i) Flash smelting - UBC/INCO

The initial two-year cooperative project has been successfully completed and a final report has been issued. Based on the data generated, a new shared-cost project with a budget of $529K over three years has been initiated. The major objective will be to develop a mathematical model which can be used to optimize burner design and operating parameters for flash smelting/converting of copper and copper/nickel mattes. Results of the project will be directly applicable to Inco's planned smelter modernization at Sudbury.

ii) Zinc pressure leach modelling - UBC/Cominco

This three-year project has been successfully completed and a final report has been published. A new three year shared-cost project has been initiated, with financial participation from Cominco, HBMS, Kidd Creek, Noranda and Sherritt Gordon. The objective is to determine the applicability of the zinc pressure leach model, developed in the initial studies, to lower grade zinc concentrates and to modify the model where necessary to compensate for concentrate composition. A second objective is to develop and evaluate methods for recovering high purity sulphur from the leach residue.

iii) Conversion of SO_2 to sulphur - McMaster/ESI

The initial project proposal, despite CANMET and ESI (Engineered Systems International) support, was turned down by NSERC as a result of their "peer review" process. A new proposal involving a potentially patentable innovative approach has been submitted by McMaster for CANMET/NSERC consideration. Industry support for the new proposal is presently being solicited.

Industry support for testwork at the ESI demonstration plant at Dofasco has not yet been forthcoming. Inco has visited the plant and shown the most interest, but has made no commitment. Syncrude has recently been contacted and the interest of other potential participants will continue to be pursued.

d) CANMET/Manitoba MDA projects

i) Pyrrhotite (Po) rejection - INCO Thompson

This five-year project has been successfully completed and a final report has been published. Discussions have been held with Inco on possible new shared-cost MDA projects as a follow-up to the present project, subject to a renewal of the MDA agreement.

ii) Gold/silver recovery from zinc pressure leach (ZPL) residues - HBMS

All work on this four-year project has been successfully completed and final reports covering precious metals recovery from ZPL sulphide and oxide residues have been issued. Implementation of the technology at HBMS will be dependent upon successful completion of the planned smelter modernization.

iii) Metal recovery from oxide tailings - HBMS

All work on this four-year project has been successfully completed and a final report is presently being prepared for publication. Implementation of the technology at HBMS will be primarily dependent on economic factors and successful completion of the planned smelter modernization.

iv) Zinc recovery from copper concentrate - HBMS

A project has been initiated to improve the Zn/Cu separation efficiency in the HBMS mill. Preliminary studies using column flotation were carried out at CANMET, but were not successful. Investigations are continuing, including fundamental studies on factors affecting the efficiency of techniques for Cu/Zn separation.

e) Miscellaneous CANMET/industry projects

i) DC plasma arc furnace - INCO/IRAP

This three-year project has been completed and a final report has been issued. To date Inco has not made any decision on implementing the technology for commercial application.

ii) Tuyere injection - UBC/Canadian Liquid Air

A one-year shared-cost ($74K) project has been initiated with UBC and Canadian Liquid Air to study accretion formation in tuyere injection processes and to develop a mathematical model which would predict the shape, size, characteristics and extent of accretion growth in metallurgical submerged injection operations.

iii) Metal recovery from smelter slags

CANMET has been carrying out laboratory studies to develop attractive methods to reduce metal losses in pyrometallurgical slags. Systematic studies were carried out on the effects of adding solid reductants (graphite, iron, pyrrhotite) on the recovery of metals in a matte or metallic alloy phase. The effect of cooling rate was also examined. Both iron and graphite enhance the recovery of metals in the matte phase, with the latter having a more noticeable effect. Slow cooling is detrimental to metals recovery. However the effects of metal/sulphur ratio on overall recovery needs further study.

Future Directions:

CANMET will continue to work closely with the nonferrous smelter industry in the development of improved technologies for SO_2 control, with particular emphasis on cooperative CANMET/industry projects, funded through DRIE(ISTC), provincial MDA's, Subsidiary Agreements on Economic Development or new programs with Environment Canada. CANMET will also continue to promote and support cooperative NSERC/university/industry projects related to nonferrous extraction/refining and SO_2 control technologies.

Outputs:

Contracts

- Reqn. 5-9030, "Develop sulphur reducing mineral beneficiation techniques and perform evaluation tests at the smelter"; INCO Thompson. S.A. - W.J.S. Craigen.

- Reqn. 5-9220, "Metal recovery from oxide tailings residues"; HBMS. S.A. - W.J.S. Craigen.

- Reqn. 9-9512, "Accretion formation in submerged injection processes"; University of British Columbia and Canadian Liquid Air. S.A. - D.T. Liang.

Publication

- Mikhail, S.A., Webster, A.H., and Laflamme, J.G.H., "Selenium distribution in copper/copper oxide melts"; Canadian Metal. Quart. 28:241-249; 1989.

Reports

- INCO Thompson, "Development of sulphur reducing mineral beneficiation techniques" (Contract 5-9030); October 1989.

- Brimacombe, J.K. and Richards, G.G., "The flash smelting of copper concentrates; a pilot study of the flame"; February 1990.

- Solar, M.Y., "DC plasma versus AC submerged arc electric furnaces"; Projects Benefit Executive Summary, INCO Limited; April 1989.

- Westland, A.D. and Webster, A.H., "Distribution of molybdenum between slag, copper matte and copper metal at 1300°C"; Division Report MSL 89-5 (J). Draft.

Project 30.47.03: Sensor Development
Project leader : J.M. Skeaff

Objective:

Opportunities exist for the application of ceramic-based, on-line, real-time,

high temperature sensors for environmental and process control in such areas as the monitoring of SO_2-SO_3, As_2O_3 and F-bearing species in process off-gases, as well as metal ion sensors for use in molten metals, mattes and slags.

The objective of this project is to investigate the development, from demonstration in principle to commercial application, of ceramic-based sensors for important species such as SO_2-SO_3 and As_2O_3 in gases and metals in matte, slag and metal phases which occur in pyrometallurgical systems.

Highlights and Achievements:

This is a new project in which experimental work on the development of an industrial SO_2/SO_3 probe has been initiated. Equipment required for the electrochemical characterization of ionically conducting ceramics at elevated temperatures has been assembled and a unique concept has led to a proposal to a lead smelter for the development of an electrochemical method for the determination of lead dissolved in lead blast-furnace slags.

Future Directions:

Effort in the future will focus on the cooperative development of a SO_2-SO_3 probe with industry, as well as a sensor for determining the levels of lead oxide dissolved in lead blast-furnace slags.

Outputs:

Contract

- Reqn., 6-9066 "Development of a solid state sulphur probe for use in pyrometallurgical processes (UP-M584)"; Ecole Polytechnique S.A. - J.M. Skeaff.

Patent

- Kinchnerova, J., Skeaff, J.M. and Bale, C.W., "Solid state arsenic probe for use in pyrometallurgical processes"; U.S. Patent No. 4, 842, 698; June 27, 1989 (assigned to CPDL).

Project 30.47.04: Ironmaking
Project leader : M.C. Campbell

Objective:

CANMET (MSL and ERL) are jointly funding a study on future ironmaking processes. CSIRA, CCRA, Stelco, Algoma, Ontario Hydro, Canadian Liquid Air, National Slag and Union Gas are sharing the costs with CANMET. The contractor is Steltech of Hamilton, Ontario. The supporters of the work coordinate efforts through a steering committee.

The study is to identify, analyze and critically assess those technologies most likely to be used over the next 20 years. These include existing and new technologies. Participants wish to determine the impact on future demand for iron ore, coal and various energy commodities as well as the impact on the Canadian steel industry. CANMET seeks some objectivity in reorienting its research directions.

Highlights and Achievements:

The essence of the study is:

i) to reduce the huge volume of available information to a manageable size,
ii) to assess the views of a wide range of international experts,
iii) to present the information to a workshop of interested parties in Canada, and
iv) to prepare a final report summarizing findings and opinions and recommending future Canadian actions.

The first two items have been completed. The contractor has reviewed the literature and categorized existing and emerging technologies for easier comparative analysis. Visits have been made to Canadian, European, Japanese, Korean and American organizations involved in evaluating and developing ironmaking technologies. A complete information report is currently being prepared by Steltech.

Future Directions:

The workshop will be held June 14-15, 1990 in Hamilton. The summary of discussions on technologies and Canadian options will be reported in September 1990.

Hydrometallurgy

Project 30.52.01: Gold
Project leader : T. Cienski

Objective:

To optimize existing processes and to develop new methods for recovery of gold from leach liquors.

To investigate alternate leaching processes applicable to refractory gold ores.

To characterize the mineralogy of gold in refractory ores in order to relate physical and chemical properties to mineral processing and metal extraction.

The main focus of the CANMET Gold Project is to provide better understanding of the nature of refractory ores and to develop improved or new technologies which will allow for treatment of such ores economically. Environmental acceptability

of ore treatment and extraction methods is a prime consideration in the implementation of new technology.

The research includes alternatives to roasting, cyanidation and carbon adsorption. A Technical Advisory Committee composed of industry representatives meets semi-annually to review and advise on projects.

Appropriate seminars serve the purpose of technology transfer and of making the gold mining and processing industry aware of the research trends and of the available solutions to existing problems. As well, a newsletter on current work and topics of interest is distributed to interested parties semi-annually.

Highlights and Achievements:

a) Mineralogical investigations

The distribution of submicroscopic gold in ores, particularly refractory gold ores, was the principal activity. The work, in collaboration with Surface Science Western, has attracted the interest of several companies. Nine companies (Abermin Resources, Resources Andrey Inc., Canamax Resources, Hudson Bay Mining & Smelting, Inco Gold Ltd., Lacana Mining Co., Levon Resources, Teck Corporation and Westmin Resources) participated in the CANMET contract with Surface Science. The success of the completed project has resulted in several companies contracting directly to Surface Science (e.g., Giant Yellowknife, Nerco Con, American Barrick plus several others). In addition, a major Canadian company has signed a three-year cost recovery/cost-shared joint agreement with CANMET on a mineralogical/analytical investigation of gold in refractory gold ores. Currently, work is in progress on a 100% cost recovery project on distribution of gold in a concentrate.

b) Thiourea leaching

i) Thiourea leaching

Evaluation of the response of gold ores to thiourea leaching is under way. The ultimate objective is in-situ leaching of the gold with thiourea. This is a joint work agreement with two gold producers, Lac Minerals, East Malartic Division and Aurizon, Sleepy Giant Division. Aurizon has seconded one employee to CANMET to work on this project.

ii) Gold-thiourea system chemistry

The form of gold loaded on activated carbon from a thiourea solution has been studied. The results indicate that the gold is adsorbed on activated carbon as the Au(I) thiourea complex which suggests that elution should be possible with high recovery.

The conditions of the zone of stability of the gold-thiourea complex have been established by developing Pourbaix diagrams. There are direct correlations between the different diagrams elaborated and the experimental results of gold leaching.

c) Carbon elution with sodium carbonate

A revenue generating cooperative work agreement has been signed by MSL, Centre de recherches minérales du Québec and three gold producers, Minnova, Cambior and Lac Minerals. The purpose of the work is to understand and optimize the utilization of sodium carbonate for the elution of gold loaded on activated carbon.

i) Electrowinning from carbon-in-pulp (CIP) eluate

Some lab scale work has commenced on the electrowinning of gold from (CIP) pressure stripping electrolytes to help define the process parameters. This work is mainly directed towards specific cost recovery projects and addresses current efficiency, corrosion and scaling of electrodes.

d) Ion exchange

i) Two resin system

Work was completed on a double resin system to extract gold from cyanide solutions. This permits relatively high gold loadings on a weak base resin. These resins are readily eluted compared to strong base types. The process was piloted and patents applied for.

ii) Ion exchange resins for gold and base metal cyanides

Ion exchange resins were screened for gold extraction performance. In the course of this work, gold selective resins were identified and a mechanism for this selectivity has been postulated. A selective resin is being further developed in cooperation with a resin manufacturer. Resins selective for base metals over gold have also been identified. Work continues on development of a resin system to extract both gold and base metal cyanide complexes from pulps. Gold and the base metals are separated from each other and the cyanide associated with the metallo-cyanide complexes can be recycled using CANMET's AVR process.

e) Gold precipitation with sodium borohydride

Gold precipitation with sodium borohydride has been studied. The process was successfully applied to gold thiourea, chloride, thiocyanate and thiosulphate solutions. The effects of various parameters were examined.

f) Microwave reactivation of CIP spent carbon

Conventionally CIP (carbon-in-pulp) spent carbon is reactivated in a rotary kiln heated externally with natural gas or electrical power. This heating process seldom provides uniform heat distribution and the desired temperature level in the kiln.

Carbon can be heated with microwaves to a high temperature (1000°C to 1200°C). This prompted investigation of the possibility of reactivation of the CIP spent carbon with microwaves at 2450 MHZ. CIP spent carbons were irradiated in the scale of 100.0 - 200.0 g per batch. All the reactivation tests were conducted

in a N_2-atmosphere in a silica crucible at various temperatures and retention times. Reactivation temperatures were measured with a type K-thermocouple. Reactivated carbons were evaluated in terms of gold adsorption capacity, adsorption rate, surface area, ash content, apparent density and pH. These evaluation data confirmed that microwave energy can be applied in the reactivation of spent carbon and the reactivated carbon was found to be comparable with or better than the thermally reactivated carbon. Further investigations are in progress for the evaluation of the operating and capital costs of microwave reactivation of CIP spent carbon. This work is being carried out under a cost recovery project under the Canada/Ontario Mineral Development Agreement and includes contract work by Ontario Hydro.

g) Gold recovery from Nova Scotia offshore samples

A study was initiated to evaluate the possibility of recovering gold from the Nova Scotia offshore sea bed. Two samples were collected and brought to CANMET. They were reduced and prepared for chemical analysis and physical determinations. All the assays and determinations consistently indicated that the metal concentration, including gold, in these samples was too low to be of any economic interest. Following this finding, the research work to recover gold from Nova Scotia offshore samples was discontinued.

h) Yukon placer gold recovery

This project was initiated under the Canada/Yukon Mineral Development Agreement. The main objectives were:

- To evaluate the efficiencies of individual mines through field sampling and testing of the operating sluice boxes and to advise and recommend process improvements and modifications.

- To perform laboratory work on the parameters involved in fine gold gravity recovery methods at the Whitehorse testing facility.

- To improve the level of understanding of the fine gold recovery problems amongst the present and future placer miners.

Now in its third year, this continuing program proves to be a very successful combination of the local initiative (Klondike Placer Miners Association), federal resources and expertise (IRAP, CANMET) and universities (UBC, University of Alaska).

So far nearly 20 placer operations were evaluated, resulting in some very significant improvements in the recovery of gold. A recently employed radio-tracing method dramatically reduced testing time and cost requirements.

This program is well regarded within the placer mining community and CANMET's presence contributes to the improved image of the federal authorities.

Future Directions:

Work will continue to focus on optimization of existing processes and development of new technologies for the recovery of gold from leach liquors. These technologies will ensure sustainability of the environment.

Outputs:

Contracts

- Reqn. 7-9037, "Ion probe microanalysis of gold in common sulphide minerals and implications for enhanced recovery from refractory gold ores"; Surface Science Western. S.A. - L.J. Cabri.

- Reqn. 9-9126, "Microwave power optimization for carbon reactivation"; Ontario Hydro Research Division. S.A. - K.E. Haque.

- Reqn. 9163/01, "Multi-client study of trends and new developments in gold extraction and processing technology"; Randol International Ltd. S.A. - R. Molnar.

Patents

- Awadalla, F.T. and Ritcey, G.M., "Removal of gold from thiourea, thiocyanate and thiosulphate solutions by reduction-precipitation with sodium borohydride"; Can. Patent Appl.; March 30, 1990 and U.S. Patent Appl.; 1989.

- Deschênes, G. and Ritcey, G.M., "The recovery of gold from leach solutions"; U.S. Patent Appl. No. 07/190,244; 1988 and Australian Patent Appl. No. 16059/88; 1988.

- Haque, K.E., Kondos, P., MacDonald, R.J.C. and Laforest, D., "Microwave activation of carbon"; Can. and U.S. Patent Appl. No. CA0501-4; 1989.

Reports

- Awadalla, F.T. and Ritcey, G.M., "Recovery of gold from thiourea, thiocyanate or thiosulphate solutions by reduction-precipitation with a stabilized form of sodium borohydride"; Division Report MSL 89-61(OP&J).

- Deschênes, G., Dupuis, C. and Ghali, E., "Eh-pH diagrams for the Au-$CS(NH)_2$) H_2O system"; Division Report MSL 88-117(OP&J); presented at the 13th IPMI Conference; Montreal, Quebec; June 1989; published in the proceedings.

- Deschênes, G., "Contribution a l'étude du traitement de l'or par la thiourée"; Division Report MSL 88-132(TR).

- Dufour, J. and Deschênes, G., "La thiourée: Environnementalement plus acceptable!"; Division Report MSL 89-57(J).

- Haque, K.E., Kondos, P., MacDonald, R.J.C. and Laforest, D., "Microwave activation of carbon"; Division Report MSL 89-76(OP&J) Draft.

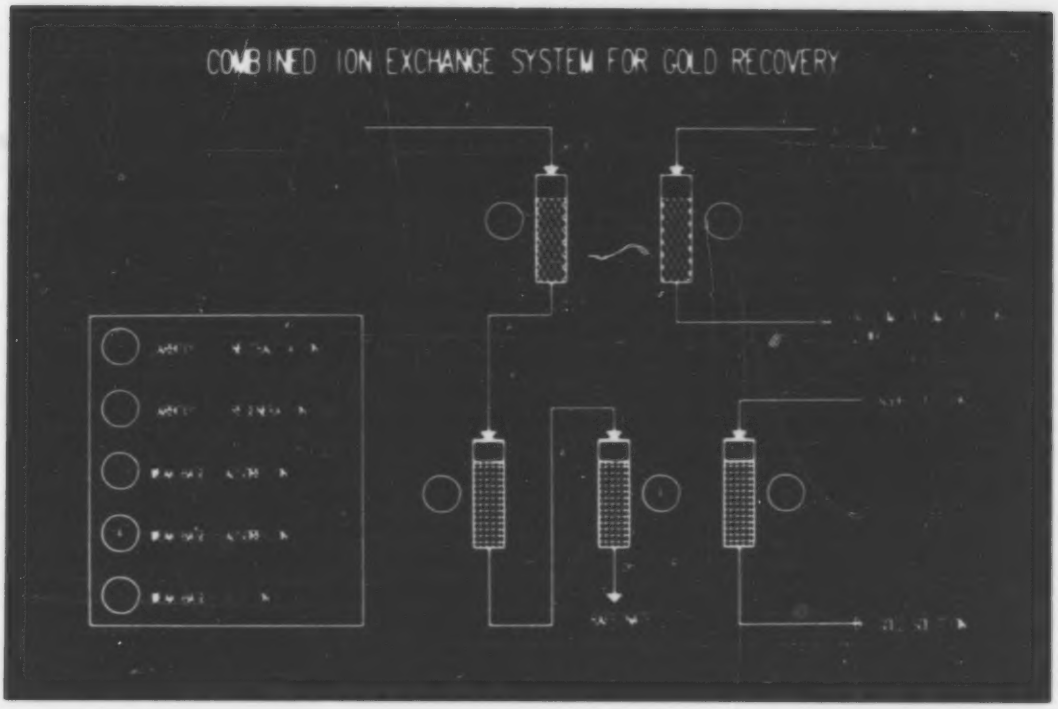

Fig. 13. Combined ion exchange system for gold recovery - conceptual flowsheet.

Project 30.52.02: Platinum Group Metals
Project leader : R. Molnar

Objective:

The platinum group metals (PGM) are currently being recovered in Canada as byproducts of base metals processing. The techniques used are well established but there is great scope for improvement of the efficiency of the recovery and separation of PGM. In addition, there is considerable interest and activity in the recovery of PGM from secondary sources, especially spent automobile catalytic converters. The secondary industry must meet particular levels of product recovery and purity in order to be economically viable. The objective of this project is therefore to improve existing PGM recovery methods and to foster the development of new industries for secondary PGM recovery based on novel technological steps.

Highlights and Achievements:

a) PGM precipitation with sodium borohydride

Precipitation of Pt, Pd and Rh with sodium borohydride has been investigated. The process has been successfully applied to chloride, nitrate and thiourea solutions. The method promises to be a technique for rapid room temperature reduction/precipitation of high purity metals from acidic solutions. There is no need for prior neutralization or acidity adjustment. It also avoids the product contamination encountered in conventional techniques such as Zn dust cementation.

b) Ion exchange separation of PGM

A technique has been developed to co-adsorb PGM and base metals onto ion exchange resins from base metal solutions. The novelty and utility of the method lies in the fact that the base metals can then be removed from the resin by water washing leaving the adsorbed PGM for recovery as a purified product. Successful bench scale studies have been carried out with a number of typical PGM leach solutions. The method may find particular use in recycle of PGM from automobile catalyst where the catalyst, and subsequently the leach liquor, are contaminated with lead which must be separated from the PGM.

Future Directions:

Work is to continue on elaboration of the ion exchange technique. Industrial partners are being sought to promote the development of the technology through the pilot plant stage. Ultimately, the borohydride precipitation technique can be married with the ion exchange technology to produce a more complete flowsheet. Future work will also be aimed at achieving better separation of the individual PGM and of expanding the scope of the technology beyond Pt, Pd and Rh to other metals in the PGM group which have not been investigated as yet.

Project 30.52.05: Copper Refining Group
Project leader : J.E. Dutrizac

Objective:

In cooperation with the Canadian copper industry, to develop by 1990, improved technologies for the characterization, deposition, control and processing of impurities in electrolytic copper refining.

Canada is a major producer of primary copper, all of which is made by smelting. During smelting, many of the impurities contained in the copper concentrates are collected in the blister copper smelter product. It is necessary to remove such impurity elements both to meet market requirements for copper conductivity and to recuperate valuable by-products. Electrorefining in a $CuSO_4$-H_2SO_4 electrolyte is universally used for this purification. The issue of impurity control is of concern as it impacts directly on tankhouse operation and profitability. Most of the Ag, Au and Se form insoluble anode slimes during electrorefining. Although

copper electrorefining has been carried out for over a century, much remains unknown about this process, and the problems associated with impurity elements are expected to intensify. If the Canadian smelting industry is to remain viable in the face of keen international competition, technological responses must be developed to overcome current problems.

Highlights and Achievements:

a) Characterization of copper anodes and anode slimes

Mineralogical and chemical investigations were carried out on anodes and anode slimes from the CCR and Kidd Creek copper refineries to elucidate the behaviour of nickel, silver and gold. Pressure leaching of the anode slimes dissolves all the copper, a significant amount of tellurium and minor amounts of selenium. Nearly end-member Ag_2Se is formed and some silver is precipitated as the selenite. Gold is detected in an oxidate phase, but it is not clear how the gold occurs. To help clarify the overall deportment of silver, the solubility of AgCl in simulated electrolytes was measured. Silver chloride solubilities are higher than the Ag concentrations in commercial electrolytes, and the implication is that the silver solubility is controlled by the selenide, cuprous ions, etc.

b) Anode passivation

The effects of O_2, Ag and Se on copper anode passivation have been partly elucidated, and the role of Cu_2O in anode passivation was identified. Examination of commercial anodes indicates that Cu_2O passivation also plays a major role in industrial practice. Current studies are focusing on Ni-O_2 interactions and their influence on anode passivation.

c) Solution purification

Literature reviews and technical evaluations are underway to ascertain the feasibility of ion exchange or solvent extraction to eliminate Ni, Sb and Bi selectively from commercial copper electrolytes.

d) Analytical methodology

Errors in the determination of nickel in copper anodes and anode slimes were identified. Round robin analytical studies were carried out with the industry on a variety of refinery feeds and products. Ion chromatography is being examined to characterize organics in copper electrolytes, and some progress has been made.

Future Directions:

Work will continue to characterize silicates, gold and platinum group elements in copper anodes and anode slimes. The characterization of organics in copper electrolytes will be examined and methods to eliminate Ni, Sb and Bi from electrolytes will be evaluated. Anode passivation will continue to be studied, and new analytical procedures for electrolytes, anodes and anode slimes will be developed.

Outputs:

Contracts

- Reqn. 9-9124, "SX-IX removal of arsenic, antimony and bismuth from copper refining electrolyte"; University of British Columbia. S.A. - J.E. Dutrizac.

- Reqn. 9-9203, "Gold Mossbauer analysis of anode slimes"; Atomic Energy of Canada Ltd. S.A. - J.E. Dutrizac.

Reports

- Chen, T.T. and Dutrizac, J.E., "A mineralogical overview of the behaviour of nickel during copper electrorefining"; Division Report MSL 89-12 (J) Draft.

- Chen, T.T. and Dutrizac, J.E., "The behaviour of gold and silver during copper electrorefining"; Division Report MSL 89-54 (OP).

- Chen, T.T. and Dutrizac, J.E., "Mineralogical characterization of anode slimes: Part 6 - Pressure leached slimes from the CCR Division of Noranda Minerals Inc."; Division Report MSL 89-123 (J) Draft.

- Chen, T.T. and Dutrizac, J.E., "The behaviour of gold and silver during copper electrorefining"; Division Report MSL 89-125 (J) Draft.

- Chen, T.T. and Dutrizac, J.E., "Mineralogical reactions of gold and silver during the electrorefining of copper anodes"; Division report MSL 89-132 (J) Draft.

- Dinardo, O. and Dutrizac, J.E., "The solubility of silver chloride in sulphate media"; Division Report MSL 89-120 (J) Draft.

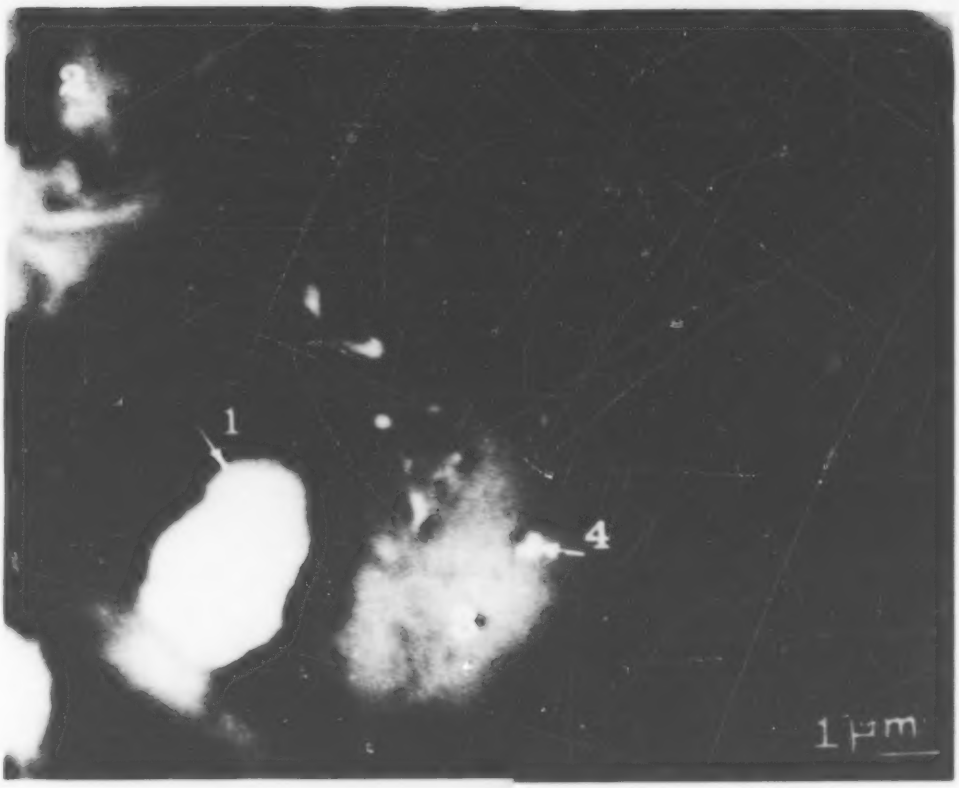

Fig. 14 Backscattered electron micrograph of a mass of gold-bearing oxidate phase in the CCR anode slimes that contains 0.1-4.5 wt % AU and 1-15% Ag (polished section). 1 - $PbSO_4$, 2 - Ag_2Se, 3 - oxidate phase, 4 - Au metal particles dispersed in the oxidate phase.

Project 30.52.06: Mineral Electrochemistry
Project leader : S.M. Ahmed

Objective:

To investigate the roles of electrochemical processes and of semiconducting and other solid state properties of sulphide minerals in relation to chemical and bacterial leaching, flotation, and prevention of acid generation due to atmospheric oxidation of sulphide tailings.

Most of the important sulphide minerals and many other oxide minerals are semiconducting in nature. It is generally known that many useful metallurgical

processes such as chemical or oxygen leaching, flotation and probably also bacterial leaching are electrochemical in nature. Atmospheric oxidation of sulphide minerals in tailings, which leads to undesirable acid generation, also involves electrochemical reactions. However, the mechanism of interfacial charge transfer in these processes and the role of the solid state (semiconducting) properties, e.,e., location of the band edges in relation to the electrochemical potentials, are not known. Hence, an understanding of the eletrochemical physics of these materials and processes can lead to significant developments and improvements in the metallurgical processes. MSL is especially well equipped to undertake such studies.

Highlights and Achievements:

a) Electrochemical studies of sulphide minerals.

More extensive electrochemical and photoelectrochemical investigations and also impedance measurements have been made on pyrite and chalcopyrite in the presence of various redox reagents. Photocurrent spectroscopy and microprobe surface analysis indicate formation of a thin iron oxide anodic film on chalcopyrite, which slows down the dissolution kinetics.

b) Control of acid generation in tailings

Based on the electrochemical studies of sulphide minerals, an electrochemical method was developed at a laboratory scale to prevent the atmospheric oxidation of pyrite and consequent acid generation. A surface chemical method has also been developed which can be used separately or in conjunction with the electrochemical method.

Noranda Technology Centre and Denison Mines are supporting the tailings investigations through letters of understanding.

Future Directions:

Investigations on tailings will be extended to materials from different sources and to a larger scale. Electrochemically assisted leaching will be studied, and investigations on the electrochemistry and relevant solid state properties of sulphide minerals will continue.

Outputs:

Publication

- Ahmed, S.M., Leduc, J. and Trudel, J., "Photoluminescence, photoelectrochemical and impedance studies of n-GaAs electrodes with and without cobalt films"; Luminescence Science and Technology, eds. C.W. Struck, B. DiBartolo and W.M. Yen; Electrochemical Society Proceedings Series, vol. PV 88-24; pp 243-257; 1989.

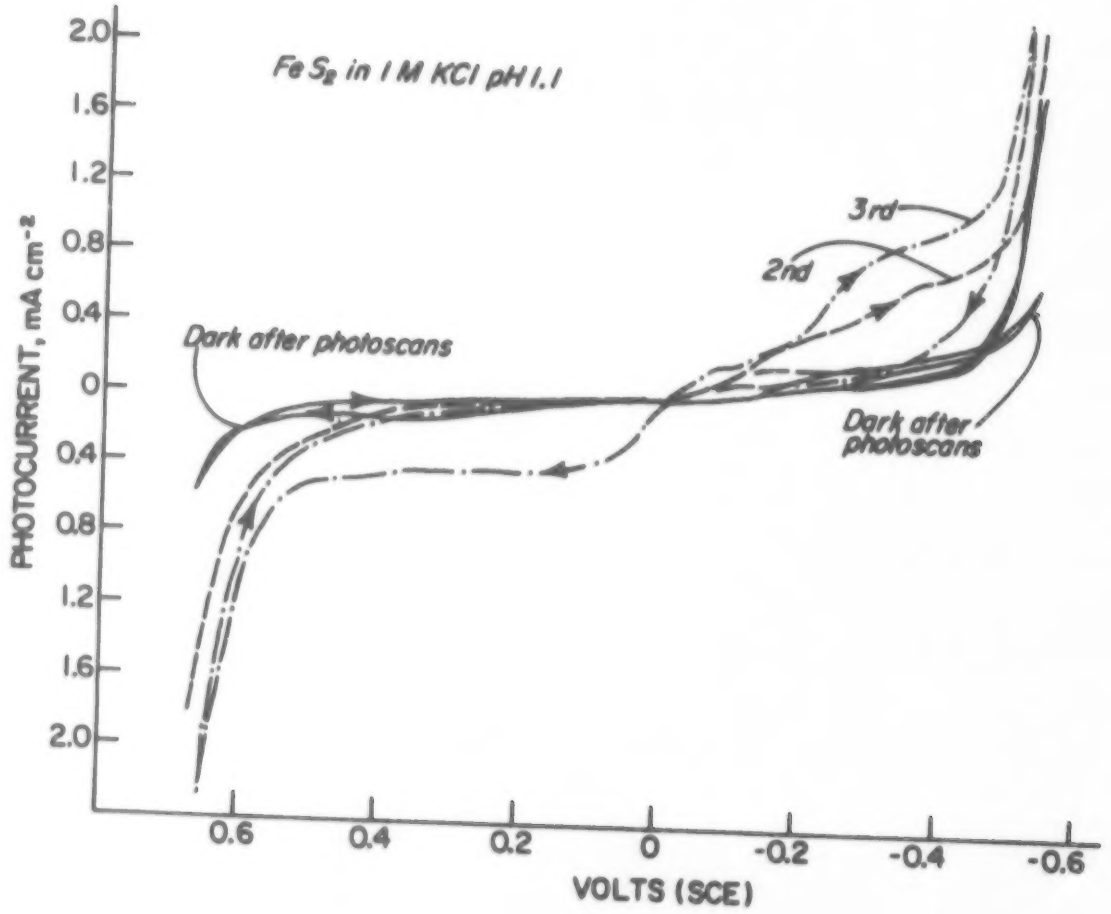

Fig. 15 Sulphide ores/tailings when exposed to air, moisture and sunlight lead to acid generation and are potentially hazardous to the environment. The figure shows how photocurrents/potentials are generated when pyrite in an electrochemical configuration is exposed to sunlight.

Project 30.52.08: Canadian Zinc Processors
Project leader : J.E. Dutrizac

Objective:

In cooperation with the Canadian zinc industry, to develop by 1993, improved technologies for zinc leaching, iron rejection, impurity control, by-product recovery and zinc electrolysis; to improve the knowledge base of the extractive metallurgy of zinc.

Canada is the world's largest supplier of zinc concentrates and is also a major producer of refined zinc metal. Although the zinc industry is well established, many challenges remain. Improved milling and flotation practices are needed to increase zinc recoveries and to reject unwanted impurities where mineralogically possible. Impurity deportment during roasting and leaching is important both for impurity control and by-product recovery. Iron control is critical, and improved technologies for producing environmentally stable iron precipitates are needed. Zinc electrolysis is an energy intensive process, and better solution purification methods are required to ensure the continuous production of zinc at high energy efficiency. In this regard, the role of organics in zinc electrolysis requires detailed investigation. If Canada's zinc industry is to continue to flourish, improved technologies and better process understanding are required.

Highlights and Achievements:

a) Characterization of zinc ores and zinc plant products

A mineralogical investigation of the relationship between the trace element content of sphalerite and its flotation response is in progress. The studies combine classical ore microscopy and modern micro-beam analytical instrumentation, and have shown some sphalerite surfaces to be enriched in Pb and Cu.

A mineralogical study of various zinc roaster products was completed. Large amounts of silver have been detected as < 0.5 μm grains associated with zinc oxide and zinc ferrite.

b) Iron precipitation/control

A study on the conversion of jarosite-type compounds to hematite in a pressure reactor at > 220°C was completed. The critical control parameters are temperature, free acidity, Fe^{3+} concentration and the amount of seed recycle. The deportment of various impurities in the conversion process was also studied. Lead and silver remain with the Fe_2O_3; most of the arsenic remains with the hematite, but some dissolves. Traces of zinc and minor amounts of sulphate are always detected in the hematite, and methods of eliminating the sulphate are being examined.

c) Zinc electrowinning

The effects of various organic and inorganic species on zinc electrowinning from industrial and synthetic electrolytes have been determined. Certain combinations

of antimony and glue have been found to maximize the current efficiency and the quality of zinc deposits electrowon from Kidd Creek electrolyte.

The effects of various inorganic species on zinc electrowinning from synthetic electrolyte have been determined, and experiments on industrial electrolytes are underway.

d) Analytical methodology

Round-robin analytical exchanges were carried out with the industry to improve the analysis of zinc processing solutions. Ultraviolet spectroscopy and combustion methods are being examined for the analysis of trace organics in zinc solutions.

Future Directions:

The behaviour of indium and gallium during jarosite precipitation will be examined along with the feasibility of precipitating Fe_2O_3 directly from zinc processing solutions. The role of various organic and inorganic species on zinc electrolysis will continue to be studied. The mineralogy of zinc concentrates and leach products will be elucidated.

Outputs:

Contracts

- Reqn. 7-9154, "Treatment of hydrometallurgical sulphur-sulphidic residues"; Cominco Ltd. S.A. - J.E. Dutrizac.

- Reqn. 8-9073, "The measurement of the solubility of oxygen in sulphuric acid leach solutions under pressure leach conditions"; University of Ottawa. S.A. - K.G. Tan.

- Reqn. 9-9075, "Development of a technique to prevent iron compound scaling in process metallurgy"; Research and Productivity Council. S.A. - J.E. Dutrizac.

- Reqn. 5-9220, "Recovery of metal values from Hudson Bay Mining and Smelting oxide tailings residues"; Hudson Bay Mining and Smelting. S.A. - W.J.S. Craigen.

- Reqn. 6-9191, "Gold and silver recovery from zinc pressure leach residues - Phase 3"; Hudson Bay Mining and Smelting. S.A. - W.J.S. Craigen.

Reports

- Chen, T.T. and Dutrizac, J.E., "Practical mineralogical techniques for the characterization of hydrometallurgical products"; Division Report MSL 89-72 (J) Draft.

- Dinardo, O. and Dutrizac, J.E., "The solubility of silver chloride in sulphate media"; Division Report MSL 89-120 (J) Draft.

- Dutrizac, J.E. and Chen, T.T., "A chemical and mineralogical study of silver, lead and cadmium in Kidd Creek zinc concentrates and roaster products"; Division Report 89-86 (J) Draft.

- Dutrizac, J.E. and Weatherell, C.J., "The relative washing of zinc and cadmium from jarosite precipitates"; Division Report MSL 89-96 (TR).

- Dutrizac, J.E., "Hydrothermal conversion of jarosite residues to compact hematite products"; Division Report MSL 89-111 (J) Draft.

- MacKinnon, D.J., Morrison, R.M., Mouland, J.E. and Warren, P.E., "The effects of antimony and glue on zinc electrowinning from Kidd Creek electrolyte"; Division Report MSL 89-73 (J) Draft.

- MacKinnon, D.J., Morrison, R.M., Mouland, J.E. and Warren, P.E., "The effects of saponin, antimony and glue on zinc electrowinning from Kidd Creek electrolyte"; Division Report MSL 89-108 (J) Draft.

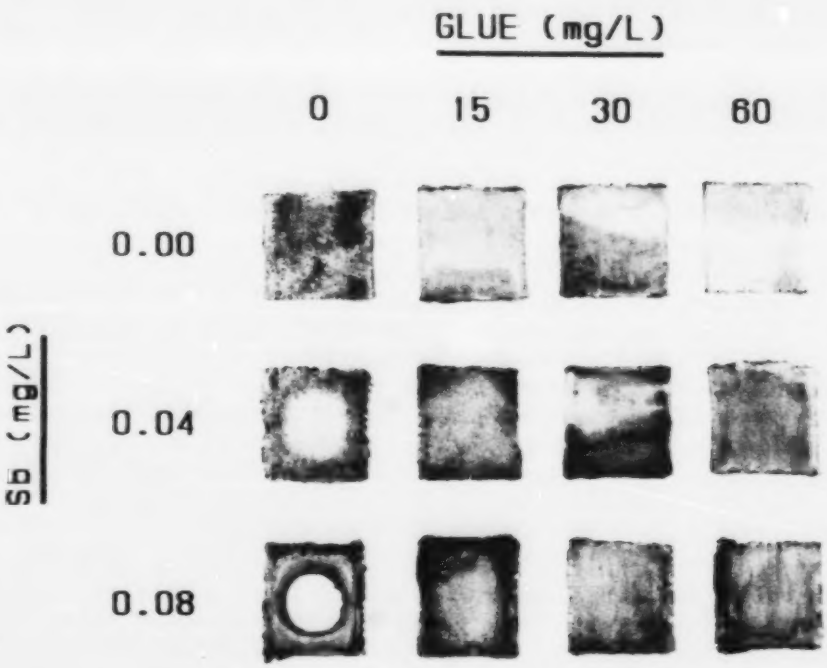

Fig. 16. Photograph showing the surfaces of 6-h zinc deposits electrowon at 500 A/m^2 and 38°C from Kidd Creek electrolyte containing various Sb + glue combinations. In the absence of glue, increasing Sb results in zinc resolution, whereas at optimum Sb + glue concentrations the deposit surface is smooth and compact.

Project 30.52.09: Chloride Metallurgy
Project leader : R.J.C. MacDonald

Objective:

To develop and evaluate viable chloride metallurgical processes which will achieve the goals of metal recoveries above 90% and the elimination of SO_2 emissions by yielding elemental sulphur or stable sulphides from bulk sulphide concentrates.

New Brunswick has the largest reserves of zinc, lead and silver in Canada; however the use of existing technology has resulted in inefficient recovery of high-value saleable products from these complex sulphide orebodies, as well as the production of large volumes of SO_2 gas. To improve metal extraction efficiency it is necessary to produce a bulk concentrate; however, because of the complexity and low grade of the bulk concentrate, it is not amenable to treatment by conventional processing technology. Increasing concern over acid rain may in the future result in the enforcement of SO_2 emission-limiting regulations. Processes which yield high metal recoveries and elemental sulphur instead of SO_2 are potentially viable alternatives to conventional technology; chloride technology offers such a process.

CANMET has been investigating and evaluating chloride processes for the treatment of these complex bulk sulphide concentrates. Current activities relate to the studies of the fundamentals of leaching in chloride media, the formation of jarosite in chloride media, the control of iron oxidation in chloride media, the cementation of copper in chloride media and the removal of cadmium from chloride solutions.

The industrial acceptance of chloride technology will be predicated on the demonstration of its technical and economic viability. Work at CANMET and under contract has largely confirmed the basic flowsheet for a ferric chloride leach process and a recently completed contract has provided a financial feasibility study and an evaluation of its potential for use on a commercial scale.

Highlights and Achievements:

a) The Ferric Chloride Leach (FCL) process

The FCL process has been developed, both within CANMET and by contract research, into a technically viable process which meets the objectives of more than 90% metal recovery and the elimination of SO_2 emissions. A contract study by Kilborn Limited provided a technical and economic evaluation of the FCL process, which has allowed CANMET to fully appraise its potential. The contract report concluded that the process appears to be economically competitive with, and perhaps superior to, conventional technology. CANMET is in the process of identifying potential industrial partners for the development of the process at the pilot plant stage.

i) Copper cementation

The purification of zinc chloride solution after $PbCl_2$ crystallization and prior to pretreatment for zinc electrolysis requires that copper be removed by cementation on iron. The kinetics of copper cementation on iron from chloride solution were studied to optimize this reaction. Both suspended iron particles and rotating iron disk systems were used. The effects of temperature (30-90°C), acid concentration (0.01 to 0.5 M HCl), ferric iron, ferrous iron, lead chloride and rotational (stirring) speed on the rate of removal of copper and on the extent of iron dissolution were studied. A temperature of 50°C and an acid concentration of less than 0.05 M HCl in the presence of process solution concentrations of ferrous, ferric and lead chloride were the best operating conditions.

b) Leaching fundamentals

The relative formation of elemental sulphur and sulphate during the leaching of sulphide was examined; more than 95% S^o formation is realized in either ferric sulphate or ferric chloride media provided that temperatures < 110°C are maintained. The morphology of the sulphur was characterized for chalcopyrite and galena. Morphological considerations suggest that the dissolution involves, in part at least, soluble HS species.

A critical review of galena leaching kinetics in ferric chloride media was carried out in conjunction with a Canadian university. The totality of the data suggests a change in the leaching mechanism at ~0.1 M $FeCl_3$. For $FeCl_3$ concentrations < 0.1 M, the rate seems to be controlled by the outward diffusion of the $PbCl_2$ reaction product through the constantly thickening elemental sulphur product layer.

c) Jarosite formation in chloride media

As part of a CANMET-EEC joint study, the formation of jarosite-type compounds in NH_4Cl-$FeCl_3$ media is being studied. The work is relevant to a new ammonium chloride leach process for complex sulphide ores and concentrates that rejects sulphate and excess iron as jarosite. The parameters affecting the formation of ammonium jarosite in NH_4Cl media were determined and defined. Of note is the fact that only minor amounts of Pb are incorporated in the jarosite structure in the presence of moderately high NH_4Cl concentrations. Silver is not incorporated in the jarosite structure because of its strong complexation with free chloride ions.

d) Iron oxidation and control

The iron oxidation and rejection step is critical for the operation of CANMET's Ferric Chloride Leach process. Efforts to optimize this step, mass balance calculations and a review of the $PbCl_2$-solubility and $FeCl_2$-chlorination data were carried out. The efficient rejection of iron requires oxy-hydrolysis at high temperature and pressure. The $PbCl_2$-solubility in chloride solutions can be extrapolated from the limited amount of data available. A simplified method was developed to calculate the reactor size for the regeneration of the $FeCl_2$ liquor.

e) Cadmium removal from chloride solution

A solvent extraction process has been developed for the removal of cadmium from a chloride solution containing other metal ions such as iron, zinc and lead. Bench scale studies have been completed. Piloting will be pursued. This process is aimed at recovery of Cd from the raffinate bleed stream in the FCL flowsheet.

Future Directions:

Work will continue on investigating the fundamental behaviour of various sulphide minerals in chloride media and on the recovery of metal values from chloride media. CANMET will continue to seek industrial partners for development of the Ferric Chloride Leach process.

Outputs:

Contract

- Reqn. 8-9048/A, "Marketability assessment of the Canada Centre for Mineral and Energy Technology (CANMET) Ferric Chloride Leach process"; Kilborn Engineering. S.A. - D.H. Bell.

Patent

- Lucas, B.H. and Shimano, D.Y., "The use of a leaching aid during a ferric chloride leach of a metal sulphide bearing material"; U.S. Pat. No. 4,902,344; February 20, 1990 and Can. Patent Appl. No. 552,378; November 20, 1987.

Reports

- Dutrizac, J.E., Ozberk, E. and Minto, R., "Lead chloride electrolysis and the conceptual design of a cell"; Division Report MSL 89-14(J) Draft.

- Dutrizac, J.E., "Elemental sulphur formation during the ferric sulphate leaching of chalcopyrite"; Division Report MSL 89-1(J) Draft.

- Dutrizac, J.E., Kobayashi, M. and Toguri, J.M., "A critical review of the ferric chloride leaching of galena"; Division Report MSL 89-80(J) Draft.

- Craigen, W.J.S., "The CANMET Ferric Chloride Leach process for the treatment of bulk base metal sulphide concentrates"; Division Report MSL 89-67(OP).

Analytical Standards and Methods

Project 30.69.01: Reference Materials
Project leader : C.W. Smith

Objective:

To support the reliability and quality of chemical and physical measurements of

mineralogical and metallurgical materials of Canadian need and interest by the preparation and certification of minerals, ores, concentrates, metals, tailings and related materials for use as reference materials for composition.

In Canada, CANMET has accepted a lead role for the production and certification of mineralogical and metallurgical CRMs through the Canadian Certified Reference Material Project (CCRMP). The progress and focus of CCRMP is reviewed annually by an Advisory Committee comprising representatives of the industrial, commercial and institutional laboratory sectors of Canada. Measurements for the certifications of CCRMP are contributed by laboratories in Canada and throughout the world. CANMET also contributes to and keeps appraised of the international focus of reference materials by participation in the Canadian Advisory Committee on REMCO (Committee on Reference Materials of the International Standards Organization).

Highlights and Achievements:

Laboratories in Canada and throughout the world purchased over 1600 units of CCRMP reference materials in this past year, generating a cost recovery revenue of some $175K. Overall demand for reference materials dropped about 15% compared to the previous (record) year. In terms of number of units, demand in Canada grew about 13% whereas foreign demand declined by about 30% compared to the previous year. Gold ore RMs continued to be among the most popular material; sales within Canada increased by 24% over the previous year, but declined elsewhere.

A new catalogue incorporating new RMs produced by CCRMP over the past several years is in production. The sales and inventory data base of CCRMP was converted to dBASE IV. The system now runs on microcomputer and incorporates some 40 custom programs. A licence has been granted to a European Community reference materials producer for use of the software.

The certification of MA-1b, a gold ore donated by Lac Minerals, Macassa Division, was completed with measurements provided by some 30 Canadian Laboratories. This is the third generation of high-grade gold ore reference materials produced by CCRMP. The technical history of this endeavour was presented at the Canadian Mineral Analysts Conference held in Timmins this year.

Progress continues on a cooperative project with the Geological Survey of Canada to provide geochemical reference materials for platinum group elements (PGE). Laboratories involved in exploration programs have sought reference material with suitable concentrations of PGE for this purpose for some time. Measurements by 15 laboratories on gold-bearing geochemical reference material UMT-1 have established certifiable values for gold (50 ppb), platinum and palladium. This material will be made available in the coming year. Five materials having diabase, peridotite and gabbro rock matrices and range of PGE concentrations have been prepared by CCRMP as candidates. An international measurement program towards certification will be carried out in the coming year.

Provisional recommended values have been established for some 20 constituents in sulphide ore tailings reference materials RTS-1 to RTS-4. These samples were

prepared by CCRMP in cooperation with CANMET/industry Mine Environment Neutral Drainage (MEND) program primarily for quality assurance of measurements. Fifteen industry and commercial laboratories provided measurements. Measurements at CANMET in the past year helped establish the shelf-stability properties of the materials, their mineralogy and major constituent concentrations. The materials were made available in March 1990.

In cooperation with the Continental Geosciences and Mineral Resources Division, four lake and four stream sediment samples representative of typical sites across Canada were made available for distribution by CCRMP. These samples have provisional values established from measurements by Canadian and international laboratories. Concentrations have been established for major to trace elemental constituents in useful geochemical ranges and these RMs are expected to find widespread application in studies related to geochemistry, exploration and even the environment.

In cooperation with the Fuels Characterization Research Laboratory and the CANMET/industry CANSPECS program, three petroleum coke samples having recommended values for ash content, sulphur and calorific value will be made available through CCRMP.

Future Directions:

The next fiscal year will see the completion of measurement programs for, and hopefully certification of, platinum group element geochemical material and pyrometallurgical sulphur RMs. An on-going analytical methodology program for constituents of copper anode slimes will resolve if a reference material is feasible.

Replacement of popular CCRMP materials as they become consumed is increasingly a necessity. Soil SO-1 was consumed in this fiscal year. Low grade gold ore MA-2a will have to be replaced in the year. Candidate materials for replacement of platiniferous materials PTC-1 and PTM-1 have been obtained.

Specific objectives will be delineated in consultation with the Advisory Committee and CANMET management early in the fiscal year.

In the long term it is expected that demand will continue to increase for reference materials with reliable values for trace constituents related to waste management, environmental control and minerals exploration.

Outputs:

Reports

- Bowman, W.S. "Certified reference materials"; Division Report MSL 89-69(R).

- Bowman, W.S. "A sales and inventory data base for CCRMP"; Division Report MSL 89-68(TR).

Publications

- J.J. Lynch, "Provisional elemental values for eight new geochemical lake sediment and stream sediment reference materials LKSD-1, LKSD-2, LKSD-3, LKSD-4, STSD-1, STSD-2, STSD-3, and STSD-4"; Geostandards Newsletter; Vol. 14, No. 1; 1990.

- Smith, C.W. and Bowman, W.S., "MA-1, MA-1a and MA-1b: Three generations of high grade gold ore reference materials"; Proceedings of the 21st Annual Conference of the Canadian Mineral Analysts; Canadian Mineral Analysts, Timmins; pp 75-128; 1989.

FY 89-90

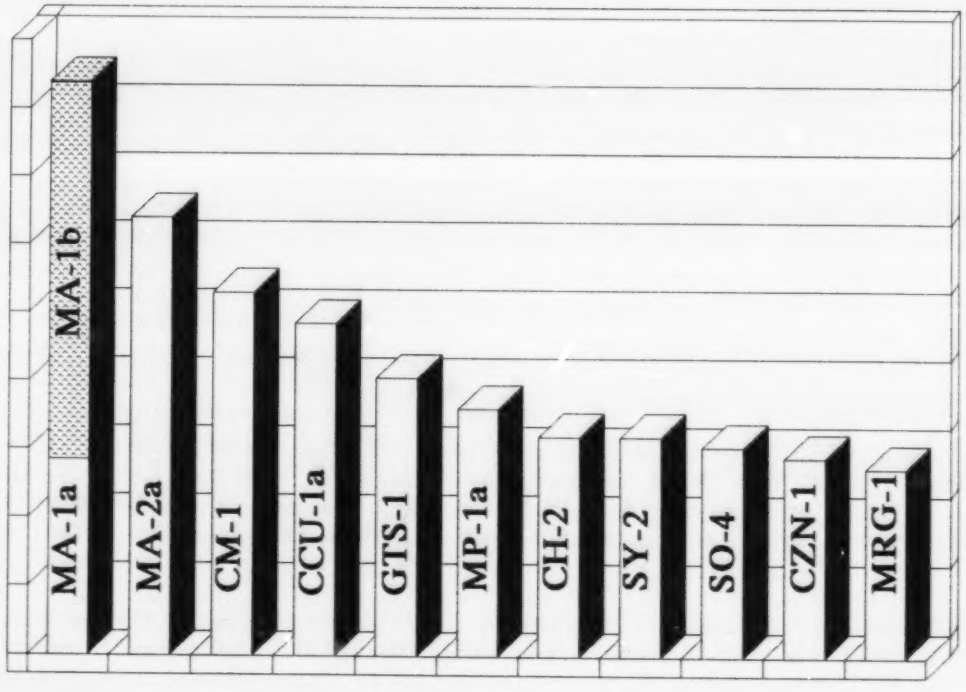

Fig. 17. Relative distribution of most popular CCRMP materials in FY 89-90 - Gold ores (MA-1a, Ma-1b, MA-2a, CH-2); Cement (CM-1); Mineral concentrates (CCU-1a. CZN-1); Zn/Sn/Cu/Pb ore MP-1a; Rocks (SY-2, MRG-1); and Soil (SO-4).

Project 30.69.02: Analytical Methodology
Project leader : J.C. Hole

Objective:

To develop and improve analytical methods, techniques, and laboratory facitilites, mainly in support of CANMET programs, and to participate in working groups and/or serve on committees of national and international organizations which develop and disseminate information on standard analytical methods.

The development of new analytical methods and techniques and the refinement of the existing methodology are essential to meet the increasing needs for faster and more accurate analytical results. The application of techniques such as infrared analysis, differential thermal analysis, thermogravimetric analysis, X-ray powder diffraction, X-ray fluorescence, inductively coupled plasma emission spectroscopy, atomic-absorption spectrophotometry and ion chromatography extend the analytical capability of the laboratories and contribute to the success of the CANMET research activities.

The International Organization for Standardization (ISO) is responsible for the establishment of international standards for a wide range of materials and products. The application of these standards facilitates orderly trade in the commodities and hence is beneficial to Canada as a large exporter. These standards can also have a significant effect on the acceptability of Canadian mineral and metallurgical products in international markets. CANMET, therefore, is taking an active role in several ISO committees and participates in other standards committees such as ASTM, etc. A number of Canadian companies actively share in this work.

Highlights and Achievements:

a) Industrial support and analytical research

CANMET is currently coordinating a joint CANMET-industry project to prepare pyrometallurgical certified reference materials for sulphur. The conventional barium sulphate gravimetric method for sulphur has been assessed with suitable radioactive tracers. Analysis of three candidate reference material has been completed.

A hydride-generation atomic-absorption method involving solvent extraction has been developed for the determination of microgram levels of antimony in ores, rocks and sediments. The method has been applied to the determination of antimony in zinc processing solutions.

High-performance liquid chromatography has been investigated for the separation of products derived from the oxidation of thiourea. A sensitive method has been developed for the determination of elemental sulphur in ores by reverse-phase adsorption and UV detection.

Fixed end-point titration has been investigated for the determination of free acid in thiourea leach solutions containing iron. A spectrophotometric method

for the determination of chloride in magnesium alloys, and ISO methods for the determination of fluoride in fluorspar and slags, have been modified and evaluated. A pyrohydrolysis method has been developed for the determination of fluoride, chloride and sulphur in various materials.

Work is continuing as time permits on combining features of both the lead and the tin fire assay methods for the determination of rhodium, iridium and ruthenium in ores.

b) Standards development

MSL has continued to make substantial contributions to the on-going work of the International Organization for Standardization (ISO) in conjunction with the Standards Council of Canada, by participation in collaborative laboratory testing and evaluation of analytical methods. MSL officers are chairmen and convenors of a number of ISO technical committees and working groups, and collaborate with 12 Canadian industries in this work.

Close involvement continues with the following ISO committees:

ISO/TC 17	- Iron and Steel
ISO/TC 69	- Application of Statistical Methods
ISO/TC 102	- Iron Ores
ISO/TC 183	- Copper, Lead and Zinc Ores and Concentrates
ISO/REMCO	- Council Committee on Reference Materials

Five interlaboratory studies of proposed international standards methods were completed as part of Canadian contributions to these committees. Numerous studies were conducted for the statistical evaluation of proposed methods. A survey of current international practice for rapid control methods of iron ore analysis was begun. MSL continues to serve as the international centre for the storage and critical evaluation of all data generated by two of these committees.

An MSL officer is assisting with the organization of an international workshop "Accuracy 91" to be held in Ottawa in 1991. An officer attended international meetings of ISO/TC 69 in Berlin in November 1989, and of ISO/REMCO in Beijing, China in May 1989.

Future Directions:

Work will continue on enhancing the analytical capabilities of the Chemical Laboratory. Emphasis will be placed on ion chromatographic techniques for determination of anions in mineral processing residues and solutions, and the determination of low levels of elements of environmental concern in ores and processing products.

The commitment to the work of international standards organizations is on-going, and complements the commitment and interest of the Canadian mineral industry. Efforts will continue towards the establishment of international standards for chemical analysis, materials sampling and testing, and interpretation of data. The international data storage facilities will be maintained.

Outputs:

Reports

- Donaldson, E.M., "Determination of antimony in ores and related materials by continuous hydride-generation atomic-absorption spectrometry after separation by xanthate extraction"; Division Report MSL 89-110 (J).

- Sutarno, R. and Bowman, W.S., "ISO/TC 102/SC 2/WG 21B. Iron ores - determination of nickel and/or chromium content by flame atomic absorption method. Statistical reevaluation of international test data - 1986"; Division Report MSL 88-152 (J) Draft.

- Sutarno, R., "ISO/TC 183. Copper, lead and zinc ores and concentrates: general expression of precision data"; Division Report MSL 89-35 (J); ISO/TC 183 N 268E.

- Sutarno, R., "ISO/REMCO. ISO Council Committee on Reference Materials: 14th meeting, Beijing, China, 1989-05-19/21"; Division Report MSL 89-64 (TR).

- Sutarno, R., "ISO/TC 102/SC 2. Iron ores - Chemical analysis. Procedure for statistical evaluation of analytical data resulting from international tests (Draft ISO/TC 102/TCR 5 - revised)"; Division Report MSL 89-85 (J); ISO/TC 102/SC 2 N 976E.

- Sutarno, R., "ISO/TC 02/SC 2. Iron ores - Chemical analysis. Working group operating procedure (Draft ISO/TC 102/TRC 4 - revised)"; Division Report MSL 89-97 (J); ISO/TC 102/SC 2 N 975E.

- Sutarno, R., "ISO/TC 69. Canadian delegation report on ISO/TC 69/SC 6, WG 1 and WG 4 meetings held in Berlin, Germany, 1989-11-13/17"; Division Report MSL 89-133 (TR).

Environment

Project 30.86.01: Tailings Characterization and Treatment
Project leader : M. P. Filion

Objective:

Solid wastes from mining operations frequently contain sulphide minerals such as pyrite and pyrrhotite. When exposed to air and water, sulphide minerals are unstable and react to produce acidic drainage. Acidic drainage is typified by low pH (1.5 to 5) and very high levels of acidity, sulphate, and heavy metals such as copper, zinc and lead. Acidic drainage can be effectively treated; however, the operation and maintenance of chemical treatment plants, for hundreds of years, is unacceptable, impractical and counter to the principles of sustainable development. Preventative technologies are required if industry is to meet current environmental challenges and remain competitive.

In response to this problem, the Mine Environment Neutral Drainage (MEND) Program was initiated in 1988. MEND is a tripartite research program which involves over 20 mining companies, CANMET, Environment Canada, DIAND, Atomic Energy Control Board, and the ministries of environment and mines from British Columbia, Manitoba, Ontario, Quebec and New Brunswick. Implementation of the research program will require a minimum expenditure of $12.5M. The program is expected to have a duration of seven years, but this may be extended as the results of research are obtained. Industry has committed one third of the project costs, subject to the federal and provincial governments matching these funds.

MEND research programs will be selected with the following objectives in mind:

- to provide a comprehensive, scientific, technical and economic basis for the mining industry and government agencies to predict with confidence the long term management requirements for reactive tailings and waste rock, and

- to establish techniques that will enable the operation and closure of acid generating tailings and waste rock disposal areas in a predictable, affordable, timely and environmentally acceptable manner.

Highlights and Achievements:

MEND research projects are provided in Table 1. In general, the projects are proceeding on schedule and budget. To date, five projects have been completed at a cost of $ 224K, fifteen projects are active and seven new projects are in the process of being initiated. The total cost for completed, active and approved projects is estimated at $ 5,506K. The respective cost sharing ratio on committed sponsorship for these projects is 43% federal government, 12% provincial government and 45% industry. Expenditures in 1989 totalled $ 1,151K and the cost sharing ratio was 47% federal government, 10% provincial government and 43% industry. CANMET has committed $ 1,573K to date over the life of the program.

Future Directions:

Work will continue on the 22 active projects shown in Table 1. The duration of these projects spans from one to five years. MEND participants will continue to identify new areas for research and sponsors for the projects. During 1990, emphasis will be placed on fundamental research initiatives such as reaction chemistry and modelling of tailings impoundments and waste rock piles.

Outputs:

Contracts

- Reqn. 8-9164, "Cement/fly ash based sealants for capping pyritic slate"; Hardy BBT and Associates Ltd. S.A. - V.M. Malhotra.

- Reqn. 8-9203, "Arsenic Geochemistry in RATAP"; Senes Consultants Ltd. S.A. - H.F. Steger.

- Reqn. 8-9173, "Potash Tailings Disposal (MDA-SK)"; Cominco Ltd. S.A. - D.G. Feasby.

- Reqn. 9-9074, "Critical Review of RATAP.BMT2"; Senes Consultants Ltd. S.A. - H.F. Steger.

MEND Reports

Project 1.16.1 Investigation of prediction techniques for acid mine drainage November 1989.

Project 2.11.1 "Subaqueous disposal of reactive mine wastes: an overview"; June 1989.

Project 2.23.1 "Draft acid rock drainage technical guide"; November 1989.

Project 2.24.1 "Manual of methods used in the revegetation of reactive sulphide tailings basins"; November 1989.

Project 4.1.1 "Field sampling manual for reactive sulphide tailings"; November 1989.

Project 5.5.1 "Reactive acid tailings sulphide stabilization (RATS) research plan"; July 1988.

TABLE 1
MEND Research Projects

Project Number	Project	Budget $(000)
1.11.1	AMD From Waste Rock - Literature Review	50.0
1.15.1	AMD From Open Pits - Equity Silver	55.0
1.16.1	Evaluation of Prediction Techniques (Phase a)	70.0*
1.16.1	Evaluation of Predictive Techniques (b&c)	63.0
1.17.1	Hydrogeological Investigation at Waite Amulet	235.0
1.21.1	Modelling of Reactive Tailings	100.0
1.23.1	Compilation of Rules for the Prediction of AMD	50.0
1.24.1	Development of Preliminary Modelling of Seepage Quality from Acid Generating Waste Dumps	285.0
2.11.1	Evaluation of Existing Underwater Disposal Sites	210.0
2.13.1	Flooding of Tailings Sites - Quirke Lake	835.0
2.13.2	Flooding of Tailings Sites - Solbec-Cupra	260.0
2.14.1	Vegetative Wetlands Over Tailings - Falconbridge	100.0
2.21.1	Dry Covers for Tailings	230.0
2.21.2	Dry Covers for Tailings - Noranda	348.0
2.21.3	Dry Covers for Tailings - Faro	200.0
2.22.1	Assessment of Hardpan	150.0
2.23.1	Documentation of Disposal Methods for Tailings and Waste Rock	75.0*
2.24.1	Vegetation Manual	35.0*
2.31.1	Dry Covers on Waste Rock - BM&S (a)	400.0
2.31.2	Dry Covers on Waste Rock - Mines Doyon	1,230.0
2.32.1	Blending and Segregation of Waste Rock	140.0
3.11.1	Treatment of Acidic Seepages Employing Wetland Ecology and Microbiology	230.0
3.12.1	Assessment of Existing Natural Wetlands Affected by Low pH/Metal Contaminated Seeps	40.0
4.1.1	Field Methods Manual - Tailings	20.0*
4.3.1	Standard Reference Materials	50.0
5.5.1	Research Program	25.0*
5.6.1	International Conference	40.0
	Total	5,506.0

* Project complete

Project 30.86.03: Liquid Effluents
Project leader : R.J.C. MacDonald

Objective:

To establish technology for the control of water pollution and to meet the standards set by regulatory agencies for the mining and processing of minerals by:

- developing technology which will eventually lead to zero discharge of contaminants and recycle of all process water.

- developing more efficient processes to recover heavy metals directly from effluents. This may include electrochemical, oxidation-reduction processes, ion exchange, and biological processes.

- developing and implementing methods to minimize metal release at source.

- evaluating and implementing means to maximize the recycle of sludges to mineral industry smelters and refineries.

- developing and/or evaluating methods of sludges dewatering for disposal volume minimization.

The ever increasing awareness and concern for protection of the environment makes it essential that economical and environmentally sound technologies be developed if the Canadian mineral industry is to remain viable.

Highlights and Achievements:

a) Arsenic precipitation from hydrometallurgical processing solutions

The experimental work on the precipitation of Co-Ni-Mg arsenates has been completed and a report is in preparation. The nature of the precipitate is strongly pH dependent and is also influenced by the rate of precipitate formation. Rapid mixing of the solutions and fast precipitation produce amorphous phases with high arsenic solubilities which are difficult to filter. Slow mixing of the solutions and slow precipitation produces well crystallized solid solution members. Complete solid solution was demonstrated in the Co-Ni-Mg arsenate ternary field.

b) Cyanide and metal recovery from gold mill solutions - CANMET AVR process

CANMET's AVR (acidification, volatilization, reneutralization) pilot unit was operated on Campbell Red Lake leach liquor to study different pH control strategy options and to determine the desirability of additional neutralization steps. Work was also carried out on improving the settling of the precipitated metallo-cyanide sludges through use of flocculants and with recycle flows. A study was initiated to improve the adsorption of HCN gas by lime slurries. The work will examine the effectiveness of various gas/slurry contact methods, for example, spraying.

In an associated study, gold leach tests were successfully performed with recycle cyanide solutions produced by AVR treatment of an effluent stream.

In another ancillary study, the thermal decomposition characteristics of the metallo-cyanide precipitates produced in AVR were studied by differential thermal analysis (DTA) techniques. The minimum temperatures and conditions required to fully decompose these materials were determined and the results were successfully tested on a larger scale.

c) Analytical development

The accepted standard methods for the determination of cyanide which involve the separation of cyanide by distillation are tedious and time consuming, and not suitable for the rapid analysis of large numbers of samples.

An automated flow injection analyzer was developed for the determination of total cyanide in gold-mill effluents and waste discharges. The system is based on the dissociation of metallo-cyanide complexes by ultraviolet irradiation of the acidified sample solution followed by separation of the resultant hydrogen cyanide by gas-diffusion through a porous Teflon membrane. The cyanide is ultimately determined by a spectrophotometric reaction. Results obtained for several gold mill effluent samples from Ontario and Quebec mines by this proposed technique were in excellent agreement with, and more precise than those obtained by Environment Canada's recommended distillation method. Total cyanide including iron cyanide complexes can be measured to levels of 5 ppb in seven minutes, and weak acid-dissociable cyanide can be determined at a sample throughput of 20 per hour. The analyzer can be adapted for automated on-site stream analysis of effluents and waste discharge for cyanide.

CANMET has arranged with Corrigan Instrumentation Ltd. of Toronto to produce and market the CANMET cyanide analyzer.

d) Acidic base metals effluent treatment

Work is under way for the development of an alternative to the lime neutralization treatment process. The aspects addressed in an alternative treatment process include: production of effluents meeting existing regulations, reduction of sludge volumes, recycling of metal contents and generation of environmentally acceptable sludges. To this direction, selective metal removal technologies are under investigation. At this particular time, solution pH, oxidation-reduction potential and temperature effects are being studied, in conjunction with cementation, adsorption and reduction techniques.

e) Well water purification and metal recovery

The removal and recovery of nickel from a deep well water has been the subject of a recent investigation. Several preliminary tests with adsorbants and resins have been successful in loading nickel and purifying the water. Subsequent elution produces an acidic concentrated nickel solution. Nickel is recovered from the solution by lime neutralization as a nickel hydroxide product, readily usable in custom smelting.

f) Membrane application in acidic effluent treatment

The utilization of membrane technology in the acidic effluent treatment is the subject of a cooperative project with NRC. Initial results indicate the capability of concentrating metals content, while purified water is produced. Other aspects of particular interest are: selectivity in metal concentration and sulphuric acid recovery and recycling.

Future Directions:

Demonstration and promotion of the economic and environmental aspects of CANMET's AVR technology will continue. The application of CANMET technology in cyanide analysis will continue and will be promoted. As well, development of on-line techniques will be investigated. Work on development of alternatives to lime neutralization and recycle of metal values will continue.

Outputs:

Report

- McNamara, V.M., "The AVR process for cyanide recovery and cyanogen control for barren recycle and barren bleed"; MSL 89-13(OP&J); presented at Gold Mining Effluent Treatment Seminars in Vancouver, B.C., February 15-16, 1989 and Toronto, Ontario, March 22-23, 1989 and published in the proceedings.

Project 30.86.04: Noxious Emissions
Project leader : J.M. Skeaff

Objective:

The objective of this project is to evaluate and where feasible to develop effective and acceptable methods for the monitoring and control of noxious elements encountered in Canadian pyrometallurgical processes. Investigations will focus on developing thermal data presently lacking for arsenides and arsenates, as well as methods for eliminating SO_2 in smelter off-gases.

The emissions of noxious elements and their compounds during pyrometallurgical processing of Canadian ores and concentrates is of concern to federal and provincial health and environmental protection organizations as well as to private industry. Of particular concern are non-ferrous roasting and smelting operations such as those associated with recovery of gold, silver, nickel and cobalt from arsenical ores, from which result SO_2 emissions as well as the emission of arsenic and mercury, and in many cases small quantities of other toxic elements such as cadmium, selenium, tellurium and lead. A need exists for more definitive data on the disposition of these trace elements in concentrates and process streams, and on modifying flowsheets or developing pollution abatement equipment for the economic removal and disposal or recovery of these elements associated with recovery of gold, silver, nickel and cobalt from arsenical ores.

Highlights and Achievements:

a) Thermochemical studies of arsenides and arsenates

An investigation of the thermochemical properties of certain arsenates and arsenides is being conducted by an equilibrium electrochemical technique in which a partially stabilized ZrO_2-CaO electrolyte is employed in an oxygen concentration cell to measure galvanic potentials. To date, thermochemical studies for the nickel arsenides and $FeAsO_4$ have been completed and preliminary data for $Pb_3As_2O_8$ have been obtained.

Under a secondment to an industrial laboratory, an MSL scientist has studied a method for the collection and disposal of arsenic from a pyrometallurgical process stream. The results to date indicate that a stable product, possibly suitable for long-term disposal, is formed. If the product proves to be stable, further work involving kinetic studies of the reaction and the development of a process will be conducted.

The data resulting from these studies can be used to predict stable condensed phases and gas compositions occurring under roasting or other pyrometallurgical conditions.

Future Directions:

Work will continue on the characterization of the thermochemical properties of the arsenates of Pb, Ni and Co. TG and DTA studies will continue on the behaviour of arsenopyrite under oxidizing and inert conditions.

Outputs:

Publications

- Mikhail, S.A., Turcotte, A.M. and Bowman, W.S. "A study of the decomposition of higher cobalt arsenides by thermal analysis"; Thermochimica Acta 153:287-296; 1989.

- Skeaff, J.M.,"Thermochemical arsenate-oxide equilibria in the system Fe-As-O determined electrochemically between 317°C and 536°C"; Canadian Metallurgical Quarterly 28:2:117-126; 1989.

- Wilson, L.J. and Mikhail, S.A., "Investigation of the oxidation of skutterudite by thermal analysis"; Thermochimica Acta 156:105-115; 1989.

Report

- Wilson, L.J. and Mikhail, S.A., "Investigation of the oxidation of the arsenic-bearing minerals niccolite and skutterudite by thermal analysis"; Division Report MSL 89-79 (OP); presented at the 28th Annual CIM Conference of Metallurgists; Halifax; August 1989.

Mineral Development Agreements

Newfoundland

During the 1989/90 wrap-up year, "Iron Ore Recovery at Wabush Mines" was the only project in progress. All other projects were completed in 1988/89 and final reports were made available through the CANMET "Open File" system.

The first three phases of the Iron Ore Recovery Project led to an increase in recovery resulting in a net benefit to the mine of about $600K a year.

Phase IV includes the optimization of a pilot circuit that had been set up within the Scully Mine concentrator. The optimization has been done by introducing an expert control system. The grinding/classification/spiral prototype circuit has been equipped with measuring and other control instrumentation. Software for the steering computer was developed and the crew was taught how to use, introduce changes to and develop the system. The system is operational and it is expected that during the next few months, when fully developed and mastered by the Scully Mine staff, it will help to further increase the iron unit recovery and to diminish production costs.

Nova Scotia

Fiscal Year 1989/90 was the wrap-up year of the Canada/Nova Scotia Mineral Development Agreement. Work was completed on five projects and the results were reported. A comprehensive study was done on the alkali reactivity of Nova Scotia aggregates and the results were presented at a two-day seminar in Halifax in May 1990. The use of local fly ash continued to increase in the province as a result of a major investigation; it was also determined that this fly ash was beneficial in the reduction of alkali reactivity of certain aggregates. Laboratory and market studies on the conversion of Nova Scotia barite resources into high value chemicals gave positive results. The deposit that provided the raw material for the study, the Lake Ainslie deposit, is relatively impure and contains significant quantities of fluorite and celestite, but is a large resource. Although the conversion tests produced specification grade products, confirmatory pilot scale tests would be needed to confirm project economics. The Technical University of Nova Scotia completed a study on the recovery of gold from sulphide-arsenide concentrate. Very high (97 - 99%) recoveries were obtained with a modified conventional cyanide process. When gold mining resumes in Nova Scotia, a process is available for gold recovery. Previous producers had shipped the concentrate to a smelter in Sweden that will no longer accept such concentrates.

The expenditure of $440K during 1989/90 brought the total expenditure in mineral technology during the agreement to $3,202K.

New Brunswick

The wrap-up year of the Canada/New Brunswick Mineral Development Agreement ended on March 31, 1990. A total of 12 federal delivery projects, involving 16 contracts, were initiated under the terms of the agreement; at the end of the

wrap-up year 15 of the 16 contracts were satisfactorily completed. In one case the contractor went into receivership and the contract was terminated.

During the current fiscal year, 1989/90, seven projects were completed, involving eight contracts. One contract was terminated due to sub-standard performance by the contractor; a substitute contract was let to complete the project and is being successfully executed.

Final reports were received during the 1989/90 fiscal year for two projects: "A Marketability Assessment of the Ferric Chloride Leach Process" and "The Alkali-Aggregate Reactivity Study". Three draft final reports were received, two for the project "The Use of Backfill in New Brunswick Potash Mines" and one for the project "Sulphide Ore Dust Explosion Control Investigation". Draft final reports have yet to be submitted for three projects: "Non-destructive Testing of Mine Shaft Wire Ropes", "Predictive Modelling of Subsidence Induced by Potash Mining" and "Development of Instrumentation for Backfill Support Monitoring". These projects remain under close review by the Scientific Authorities and the reports are expected shortly.

Quebec

The MDA-Quebec was signed in 1985 and covers a wide range of activities and projects related to the mineral industry under 11 programs. The total value of the Agreement was initially $100M cost-shared 50/50 between the provincial and federal governments.

The Agreement was amended recently to extend the final wrap-up year to March 31, 1992. As of March 31, 1990 a total of $95.8M has been expended. An additional amendment is forthcoming to raise the value of the Agreement to $112M and to fund the operation of the Asbestos Institute until March 1993.

On the processing side, projects involved the following:

i) In-situ leaching with thiourea

A feasibility study of using thiourea for in-situ leach of gold at a Quebec Mine is in progress. The geological characteristics of some of these deposits are believed to be amenable to such treatment.

ii) Knowledge based automatic control in processing plants (KBAC)

The purpose is to adapt KBAC methods to mineral processing circuits and to select the best ones for transfer to the plant. These KBAC theories have not been widely adapted to mineral processing because they are state-of-the-art. The project contributes to the development of advanced mineral processing modelling and control which will be required for the nineties.

iii) Gold circuits - improving gold recovery

An evaluation of mill circuits was completed at Lac Shortt and Dumagami with follow-up recommendations. Preliminary test work has shown that modifications

in the cycloning and regrinding circuits would improve gold recovery. Further simulation work using computer programs such as BILMAT is planned for the next fiscal year.

Ontario

Mining Technology research was the principal activity under the Research and Development component of this Agreement. Under the Economic Development component, some funds were specifically allocated for work involving microwave technology. Under this program work was initiated on a cost recovery basis for application of microwave energy to reactivation of carbon in gold carbon-in-pulp circuits. This work also involved contract work with Ontario Hydro's Research Laboratories.

Contract

- Reqn. 9-9126, "Microwave heating for carbon activation"; Ontario Hydro Research Laboratories. S.A. - K.E. Haque.

Manitoba

Under the Research and Technology Sector of the Canada/Manitoba Mineral Development Agreement, CANMET's Mineral Sciences Laboratories is responsible for delivery of the federally funded Processing Technology projects. During FY 1989/90 six federally funded processing projects with expenditures of $275K were active.

A final report on the evaluation of process technology for recovery of Au/Ag from HBM&S zinc pressure leach oxide residues has been completed. The most promising approach is one using a lime boil silver enhancement treatment (SET) followed by conventional cyanidation. Using this method, silver extraction from pressure leach oxide residue was over 95%. The report indicates that the proposed process is both technically and economically feasible.

A final report on the reduction of SO_2 emissions through rejection of pyrrhotite has been approved. Although the work has been successful in meeting objectives, follow-up work is essential to meet future SO_2 emission regulations.

The project on applied mineralogy being carried out through the University of Manitoba has been very active throughout this final year. Final reports on the Stall Lake, Chisel Lake and Namew Lake ores are now complete. This project has been very successful and popular with the industry and has led to efforts to obtain a complete facility at the University of Manitoba with industry support.

All testwork has been completed on the recovery of metal values from old HBM&S oxide tailings. A final report including engineering and economic feasibility will be issued shortly. The work was done under contract by Sherritt Gordon. These tailings have been stockpiled since the commencement of the present zinc leach plant.

Under a cost-shared contract, work on improving the recovery of zinc through

application of column flotation resumed at Ruttan in 1989. Loss of staff had caused interruption since 1987/88. A report will be completed shortly.

A final report on D-cracking of concrete in the Winnipeg area and main rural roads has been completed. Remedial measures to alleviate this problem caused by swelling of aggregate are included in the report.

Although work on the Bird River chromite under the MDA is basically complete, both CANMET and Manitoba Energy and Mines are maintaining an interest and are looking at possible further studies.

The Minerals Technology Research and Development Sector concluded their successful series of seminars on mining and processing projects with a combined "wrap-up" review" in Winnipeg, November 30-December 1, 1989. Over 130 delegates from industry, government and academia participated. Highlights of the meeting were addresses by provincial Mines Minister, The Honourable Harold Neufeld and federal Minister of Energy and Mines, The Honourable Jake Epp. In addition a very stimulating panel session which featured Manitoba Mining Industry CEO's and federal and provincial government representatives concluded the proceedings.

Saskatchewan

The mineral technology component of the Saskatchewan Mineral Development Agreement ended in March 1989.

Yukon

The original Sub-Agreement with the Yukon ended March 31, 1989. Within this agreement approximately $600K was expended on research on placer technology. CANMET was involved in an advisory function.

For 1989/90 a new one-year agreement was negotiated and funded with Department of Indian and Northern Affairs resources. CANMET was involved in developing a continuation of the placer program for this one-year period.

The objectives of this work were:

- To evaluate the efficiencies of individual miners through field sampling and testing of the operating sluice boxes and to advise and recommend process improvements and modifications.

- To perform laboratory work on the parameters involved in fine gold gravity recovery methods at the Whitehorse testing facility.

- To improve the level of understanding of the fine gold recovery problems amongst the present and future placer miners.

Now in its third year, this continuing program proves to be a very successful combination of the local initiative (Klondike Placer Miners Association), federal resources and expertise (IRAP, CANMET) and universities (UBC, University of Alaska).

So far nearly 20 placer operations have been evaluated resulting in some very significant improvements in the recovery of gold. A recently employed radio-tracing method dramatically reduced testing time and cost requirements.

Report

- Clarkson, R., "The use of radiotracers to evaluate gold losses at Klondike Placer Mines - Phase II"; Klondike Placer Miners Associates and CANMET; March 1990.

Northwest Territories

CANMET provided coordination and scientific advice services to the Canada/NWT MDA through the Northern Technology Assistance Program (NTAP). In 1989/90 three NTAP projects involving processing technology and cost-shared with industry were carried out.

1. A project on "Toxic Stabilization and Precious Metals Recovery from By-Products at Nerco Con Mine" was initiated. Total costs were $101K; 50% being covered by the industry. This project is aimed at recovering high values of gold contained in arsenic plant residue, roaster calcines and final tailings feedstock as well as at producing an environmentally acceptable residue.

2. "Gold Recovery Improvement Investigation at the Giant Yellowknife Mine" cost $55K in 1989/90 of which $45K was covered by Giant. It is expected that the results of this project, when implemented, will lead to increased recovery of at least 1 to 1.5%. Each percent increase in recovery greatly increases the efficiency of the Giant operation.

3. "High Temperature Gas Filtration at Giant Yellowknife" cost $375K in 1989/90 of which Giant covered $75K. Successful completion of the filtration test work will enable Giant to detail arsenic purification plant design. The plant will employ 12 to 15 people and will be capable of producing 70,000 t/year of high quality arsenic product.

FUELS TECHNOLOGY SUB-ACTIVITY

Fluidized Bed Combustion (FBC)

Project 50.62.06: FBC Systems for Coal
Project leader : D.T. Liang

Objective:

To develop techniques for determining the capacities of the limestone candidates for sulphur removal, to characterize solid reaction products from various forms of coal combustion (e.g. pulverized, AFBC, CFBC and PFBC) and to develop a mathematical model for predicting sorbent performance in circulating fluidized

bed combustors. To evaluate methods for NO_x control either during or post combustion of coal and to identify the most promising technology in a bench scale apparatus.

Highlights and Achievements:

a) Thermal analysis of FBC products

A thermogravimetric (TG) method was developed at CANMET for the analysis of reaction products from fluidized bed combustion processes in which limestone is added for sulphur capture. The method has been modified and refined to include H_2O, $Ca(OH)_2$, $CaCO_3$, carbonaceous materials, $CaSO_4$ and Fe_2O_3 in the samples. The viability and accuracy of the method were verified by analyzing reagent grade mixtures and fluidized bed samples from a Canadian demonstration scale combustor (the Chatham plant) and comparing the results with those of conventional methods. The TG method may be used to monitor the efficiency of coal combustion and limestone utilization in fluidized bed combustors.

b) FBC emission abatement

MSL's 100 mm dia. CFB combustor was employed to study the effect of halides present in some fuels on the emissions of CO, NO_x and SO_2. Calcium chloride and calcium bromide were added to the combustor burning Devco Prince washed coal in separate tests. The results were compared with those from similar tests carried out in a bubbling FB combustor at ERL. Dramatic increases in the emission of carbon monoxide and NO_x were found in both cases. These results suggested that the incineration of halogen-containing organics in CFB combustors, as proposed in some commercial designs, may lead to the production of unacceptable levels of these pollutants.

The TG sorbent evaluation technique developed for the testing of limestones destined for CFB combustors has been refined to accommodate larger sample sizes with wider size distributions. It has also been used in the evaluation of sample candidates for the lime injection process for conventional pulverized coal boilers in which the limestone particles are typically small and have a very short residence time. Work on this TG analyzer is continuing and will be expanded to include preliminary testing of the removal of NO_x, CO_2 and other pollutants such as metals in vapour phase.

Future Directions:

The TG Sorbent evaluation technique will continue to be developed and the method will be validated and refined by mathematical modelling and comparison with field data. The technology developed in CANMET will be transferred to industry via licensing agreements.

Outputs:

Publications

- Anthony, E.J., Liang, D.T. and Hamer, C.A., "Sulphur capture and reduced

sulphur forms in circulating and bubbling fluidized bed combustors"; Proceedings of the 1989 Technical Meeting of the Combustion Institute, Canadian Section; p 130.

- Liang, D.T., Wilson, L.J. and Hamer, C.A., "Characterization of limestone sorbents for use in circulating fluidized bed combustors"; Proceedings of the 1989 Technical Meeting, of the Combustion Institute, Canadian Section; p 133.

- Mikhail, S.A. and Turcotte, A.M., "A TG method of analysis for use in monitoring the efficiency of fluidized bed coal combustion processes"; Proceedings of the 18th North America Thermal Analysis Society (NATAS) Conference; San Diego, CA; ed. I.R. Harrison; pp 103-111; 1989.

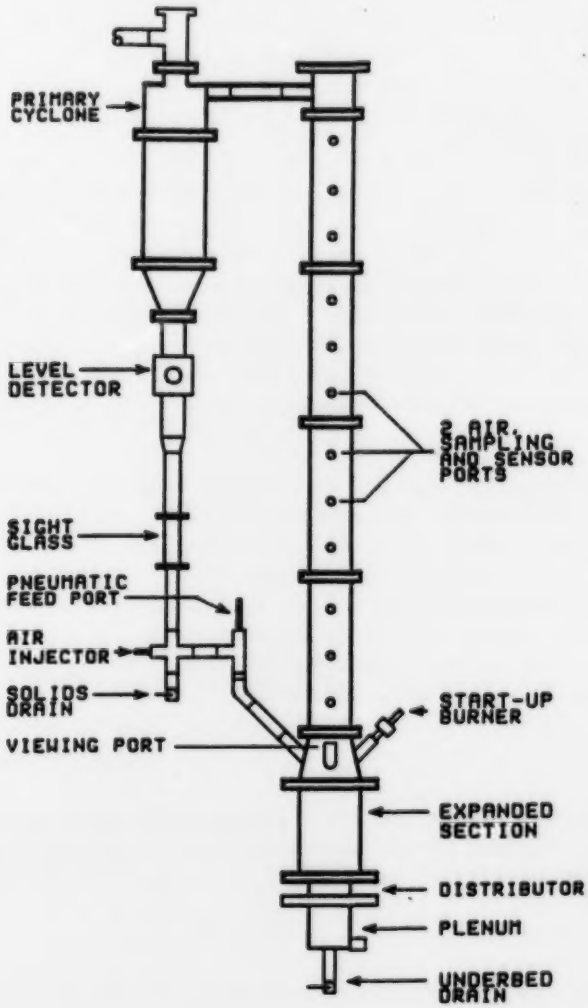

Fig. 18. A schematic diagram of the MSL 100-mm diameter circulating fluidized bed combustor.

PART B. BUSINESS DEVELOPMENT

COST RECOVERY CONTRACTS

General

Cost Recovery No.	Project Leader	Title
25545	W. Craigen	Evaluating tax payer's claims on scientific research

Chemical Laboratory

Cost Recovery No.	Project Leader	Title
50083	D. Carson	Equipment verification
50142	L. Dalton	X-ray fluorescent testing on glass samples
50182	L. Dalton	X-ray fluorescent spectrometry

Extractive Metallurgy Laboratory

Cost Recovery No.	Project Leader	Title
50028	R. McCready	Assessing rotary-biological-contactors (RBC) to remove organics from recycled water
50029	G. Tan	Silver refining process development plant design
50036	D. Liang	Combustion of coke dust in circulting fluidized bed combustor
50048	R. Molnar	Development of beryllium chemical plant technology
50073	R. Molnar	Degradation of copper electrolyte
50074	R. McCready	Consultant for microbiology study
50078	A. Dubreuil	Dielectric development program for air purification systems based on ozone
50088	R. MacDonald	Application of microwave energy to phenacite leaching
50089	D. MacKinnon	Zinc electrowinning
50090	R. McCready	Biological mitigation of acid drainage in seepage channels

Extractive Metallurgy Laboratory (Cont'd)

Cost Recovery No.	Project Leader	Title
50092	H. Webster	Reduction of titanium dioxide
50096	G. Deschênes	Consulting on thiourea processing for a gold deposit
50100	R. Molnar	Iron solvent extraction test program
50107(A)	G. Deschênes	Use of sodium carbonate in a carbon-in-pulp (C.I.P.) circuit
50107(B)	G. Deschênes	Use of sodium carbonate in a C.I.P. circuit
50107(C)	G. Deschênes	Use of sodium carbonate in a C.I.P. circuit
50110	M. Campbell	Metallurgical test program on a uranium deposit
50113	C. Hamer	Testing of limestone for sulphur capture capability by thermogravimetric analysis
50122	C. Hamer	Recovery of tin
50126	S. Mikhail	Examination of strontium carbonate
50127	J. Skeaff	Calcium reduction of vanadium pentoxide
50140	R. MacDonald	Microwave reactivation of carbon
50141	S. Mikhail	Examination of strontium carbonate by high-temperature microscopy
50144	G. Deschênes	In-situ leaching of gold using thiourea
50150	D. Shimano	Copper/silver recovery from a deposit
50158	R. Molnar	Solvent extraction testing
50162	R. McCready	Provision of educational material on microbiology
50164	S. Ahmed	Control of oxidation of sulphide minerals in tailings
50165	R. Molnar	AVR bench scale evaluation
50174	R. McCready	Degradation of organics in tailings effluent
50175	S. Mikhail	Examination of rutile concentrate by TG-FTIR

Mineral Processing Laboratory

Cost Recovery No.	Project Leader	Title
25516	M. Cristovici	Upgrading and pelletizing ilmenite ore fines
25527	D. Laguitton	Process control and expert system for oil sand extraction
50001	V. Malhotra	Utilization of waste from fluidized bed operations as a cementitious material
50012	P. Mainwaring	Relation of magnetite liberation on ultimate iron recovery

Mineral Processing Laboratory (Cont'd)

Cost Recovery No.	Project Leader	Title
50018	G. Mathieu	Treatment of brasque
50020	V. Malhotra	Sealing pyritic slate outcrops
50021	L. Cabri	Improved understanding on the amount and nature of microscopic gold
50022	L. Cabri	Sphalerite floatability
50024	P. Mainwaring	Liberation analysis of a mill feed
50025	L. Cabri	Mineralogical examination of the platinum group elements
50030	J. Canaday	Investigation of Hyceram for sensor applications
50031	G. Mathieu	Separation of pyrite from black pyrochlore
50032	J. Jambor	Mineralogical investigation
50033	J. Wilson	Mineralogical analysis
50050	T. Cienski	Column flotation investigation on a copper concentrate
50051	L. Cabri	Electron microprobe analysis of platinum minerals
50055	T. Cienski	Column flotation investigation on primary cyclone overflow
50057	V. Malhotra	Foam concrete
50059	W. Cameron	Training in techniques of froth flotation related to mineral beneficiation
50064	J. Canaday	Preparation of hydronium sample
50067	M. Raicevic	Flux recovery by Sala HGMS
50068	W. Petruk	Image analysis study on copper tailings
50070	P. Mainwaring	Image analysis for oilwells
50075	G. Feasby	Dolomite comparison
50076	J. Wilson	Mineralogical analysis of the spiral circuit
50077	G. Mathieu	Techniques de nettoyage d'un chargement de coke contaminé par la magnétite
50081	T. Wheat	Calcination of clays & shales samples
50086	D. Quon	Calcination of shales
50093	P. Andrews	Fluorite recovery
50094	W. Petruk	Image analysis on limestone samples
50095	K. Moon	Improve the recovery of fine sulphide minerals using electroflotation
50097	G. Mathieu	Recherche sur des techniques de décontamination de coke
50101	M. Cristovici	Conduct cost estimate for a recovery flowsheet
50102	S. Wang	Viscosity measurements of slag samples
50103	V. Malhotra	Training in concrete technology
50105	L. Kuehn	Wet scrap reprocessing
50108	W. Petruk	Calcine samples for assaying
50109	J. Lamothe	Concassage de dolomie

Mineral Processing Laboratory (Cont'd)

Cost Recovery No.	Project Leader	Title
50111	J. Lamothe	Testwork on graphite ore
50114	W. Petruk	Size distribution analysis
50115	L. Cabri	Distribution of gold, platinum and palladium
50116	J. Lamothe	Characterization of calcium and strontium residues by X-ray fluorescence and SEM survey
50117	W. Petruk	Mineralogical study of feed and of tin concentrate
50119	J. Lamothe	Heavy media separation of manganese ore
50120	D. Quon	Calcination of clay samples
50121	W. Petruk	SEM photographs of clay
50123	J. Lamothe	Concassage de dolomie
50124	V. Malhotra	Consulting on fly ash utilization
50129	W. Petruk	SEM analysis of filter samples
50130	J. Lamothe	Preliminary testing on graphite ore
50131	J. Szymanski	Literature review for crystallographic data on gypsum, anhydrite and hemihydrate
50132	G. Feasby	Testing on graphite ores
50136	S. Wang	Viscosity measurements
50137	J. Soles	Petrographic analysis and alkali reactivity test
50138	G. Feasby	Analyses of calcium/magnesium residues
50139	V. Malhotra	Mechanical properties of light weight concrete
50143	V. Malhotra	Magnesite samples analyses
50146	G. Feasby	Crystal peak garnet
50147	T. Negeri	Ore selectivity optimization study
50149	G. Feasby	Recovery of muscovite from gold mine tailings
50151	L. Kuehn	Column flotation
50153	G. Mathieu	Concentration of vanadium-bearing magnetite and ilmenite
50157	V. Malhotra	Testing of concrete prisms for freezing and thawing durability
50159	G. Mathieu	Charactérisation d'un coke de pétrole contaminé par de la silice
50160	J. Lamothe	Testing on graphite ore
50167	T. Wheat	Ceramics consulting
50168	T. Wheat	Ceramics consulting
50169	T. Wheat	Ceramics consulting
50170	T. Wheat	Ceramics consulting
50171	J. Lamothe	Microsieve size analyses
50172	T. Wheat	Ceramics consulting
50173	G. Feasby	Production of garnet concentrates
50183	L. Cabri	Standard for electron microprobe

INDUSTRIAL RESEARCH ASSISTANCE PROGRAM (IRAP)

Project No.	Project	Industry	Scientific Authority
L2730-0870	D.C. Plasma Arc Furnace	Inco Ltd.	J. Skeaff
L2730-1184	Process Control and Expert System for Oil Sand Extraction	Syncrude/Edmonton	D. Doyle
L2730-1199	Recovery of Platinum, Palladium, and Rhodium from Spent Automotive Catalysts	Platinum Lake	R. Molnar
L2730-1202	Improved Iron Recovery	Iron Ore Company of Canada	W. Cameron
L2730-1264	Agitated Flotation Column	Hydrochem	T. Cienski
L2730-1331	Image Analysis for Oilwells	Petrel	D. Leckie (EMR/ISPG)
L2730-1351	Development of Beryllium Chemical Plant Technology	Hecla	K. Haque
L2730-1367	On-Stream Cyanide Analyzer	Corrigan	F. Kelly
L2730-1376	Value Added Graphite Products	Stewart Lake	D. Feasby
L2730-1377	Portable Ultrasonic Concrete Tester	Techno	V. Malhotra

SECONDMENTS

From MSL

- W.D. Gould to the Fermentation Research Institute, Tsukuba, Japan.
- L.A. Kuehn to Minnovex Technologies Inc.
- V. Sivasundaram to the University of Wisconsin's Center for By-Products Utilization.
- L.J. Wilson to Noranda Technology Centre.

To MSL

- G. Balajee, N. Maffei and S. Varma from BM Hi-Tech Inc..
- J. Brandstetr from Technical University, Brno, Czechoslovakia.
- J-P. Cuif from Rhône-Poulenc Inc.
- G. McMahon and M. Saleem from Ceramics Kingston.

PATENTS

Granted to MSL

Inventor(s)	Invention	Country
K.S. Moon L.L. Sirois	Method for Analyzing Different Sulphur Forms	Canada, United States
J. Kirchnevora J.M. Skeaff C.W. Bale	Solid State Arsenic Probe for Use in Pyrometallurgical Processes	United States
A.K. Kuriakose T.A. Wheat A. Ahmad J.D. Canaday A.J. Hanson	Bonded Hydrogen Conducting Solid Electrolytes	Canada
B.H. Lucas D.Y. Shimano	Ferric Chloride Leach of Metal-Sulphide Bearing Material	United States

Filed by MSL

Inventor(s)	Invention	Country
R.G.L. McCready W.D. Gould J. Salley	Biorecovery of Selenium	Canada, United States
R.G.L. McCready C. Chalykoff J. Salley W.D. Gould J. Worgan	Biodegradation of Alkylene Glycols Utilizing Selected Bacteria	Canada
R.G.L. McCready V.I. Lakshmanan	Bioadsorption Composition, Process for Production Thereof and Process for Use Thereof	Canada, United States
K.E. Haque P. Kondos R.J.C. MacDonald D.E. Laforest	Microwave Activation of Carbon	Canada
K.E. Haque	Recovery of Dissolved Gold by Sodium Borohydride Reduction	Canada
F.T. Awadalla G.M. Ritcey	Removal of Gold from Thiourea, Thiocyanate and Thiosulphate Solutions by Reduction-Precipitation with Sodium Borohydride	Canada

LICENCES

Company	Technology
B.M. Hi-Tech Inc.	To develop ceramic materials with properties suitable for use in transducers.
Cambrian Engineering Group Limited	To market MSL's acidification-volatilization-neutralization (AVR) technology used to recover and recycle cyanide.
Laboratory of the Government Chemist	To obtain a copy of the Canadian Certified Reference Materials Project sales and inventory database system.
Lakefield Research	To use information arising from a contract on the performance characteristics of a group of flotation reagents.
50 licences in twelve countries	CAMP Agreements

TECHNOLOGY TRANSFER SEMINARS AND TRADE SHOWS

- Mineralex, First Bi-annual Mining and Exploration Exposition, Springdale, Newfoundland, May 1989.
- CANMET in Partnership with the Mining and Minerals Industries, Vancouver, May 1989.
- Northern Ontario Industrial Trade Show - 1989, Sudbury, September 1989.
- Workshop on Computer-Aided Mineral Processing (CAMP), Timmins, November 1989.
- Information Technology in Mineral Processing, Smelting and Refining, Ottawa, January 1990.
- Canadian Mineral Processors' 22nd Annual Operators Conference, Ottawa, January 1990.
- Minerals, Metals and Coal Technologies in Atlantic Canada, Halifax, January 1990.
- Globe '90, Vancouver, March 1990.

PART C. GENERAL SERVICES AND OPERATIONS

CHEMICAL LABORATORY

Manager: H.F. Steger

Summary of Analytical Services

The figures tabulated below refer to the number of analyses performed by the Chemical Laboratory in support of CANMET programs in the period from April 1, 1989 to March 31, 1990.

Project No.	No. of Determinations	Project No.	No. of Determinations
Mineral Processing			
30.05.02	22	30.69.99	17
30.05.03	3	30.70.01	235
30.05.99	54	30.86.01	67
30.13.04	178	30.86.03	1,501
30.13.05	188	30.86.04	56
30.13.07	211		
30.13.99	675		24,897
30.29.99	56		
30.37.01	39	**Metals & Materials**	
30.37.05	16		
30.46.01	10,273	70.04.03	1,017
30.47.03	5	70.04.05	121
30.47.99	278	70.15.01	4
30.52.01	4,237	70.15.02	22
30.52.02	13	70.15.03	8
30.52.03	1,174	70.15.04	187
30.52.05	440	70.26.01	3
30.52.06	15	70.26.02	50
30.52.08	2,379	70.26.05	10
30.52.09	1,052	70.42.01	303
30.52.10	28	70.42.02	66
30.52.99	1,379	70.42.05	4
30.69.01	234	70.95.01	4
30.69.02	72		
			1,799

Total number of determinations = 26,696

Occupational Health and Safety

On behalf of MSL, the Chemical Laboratory has assumed a leading role in the practical technical aspects of occupational health and safety.

For the implementation of WHMIS legislation, an introductory course was prepared and given to all MSL staff; advice was given and presentations were made to other divisions; hazard awareness stations were designed and installed; and the first complete inventory of all chemicals within MSL was made.

In the area of laboratory waste management, more than 300 hazardous chemicals were disposed of; Waste Disposal Procedures were drawn up and adopted; and leachate testing of MSL lime thickeners was initiated under MOE regulations.

MSL Network

Both MSL servers were interconnected to form one network allowing users to access the Sample Tracking System and the MSL Management Information System from 32 different locations in the 555 Booth St. complex. Four individual telephone lines were installed allowing remote access to the network via modems by using the PC Anywhere III ATERM software. The Network Courier electronic mail software was installed permitting full communication between users. An additional high capacity and high quality output laser printer was added to accommodate users wanting large quantity and high quality printing. A new tape backup system was installed allowing automatic timed backup without disturbing the day-to-day operation of the network. The MSL Management Information System software is presently being modified to respond to various demands by the software's users.

MSL Electronic Publishing

No. of Graphics Requested by Type

Overhead Transparencies	300
35 mm Slides	187
Charts	79
Mounted Display Signs	20
Technical Illustrations	20
Newsletters	14
Mock-ups	5
Reports	4
Pamphlets	3
Annual Reports	2

Presentation and graphics support was provided for the Lortie Commission Review. A computerized presentation graphics system for the production of colour 35 mm slides and overhead transparencies was researched and purchased, and the installation was fine-tuned.

MINERAL PROCESSING LABORATORY

Process Mineralogy Section

Head: W. Petruk

Summary Of Mineralogical Services

Project No.	Microprobe Hours	SEM Hours	X-ray Diffraction Hours
30.05.02	29.0	0.0	16.0
30.05.03	68.0	48.5	82.5
30.05.99	290.0	10.0	1.5
30.13.02	0.0	0.0	0.5
30.13.04	0.0	4.0	0.0
30.13.05	0.0	0.0	35.0
30.13.07	0.0	0.0	1.5
30.13.99	4.5	13.0	4.5
30.29.01	11.0	8.0	12.0
30.29.02	0.0	9.5	0.0
30.29.03	0.0	42.5	34.0
30.29.04	0.0	5.5	0.0
30.29.05	0.0	6.5	5.5
30.29.99	0.0	5.0	0.0
30.46.03	6.0	0.0	0.0
30.47.02	18.0	0.0	3.5
30.47.03	0.0	10.0	26.5
30.47.99	0.0	0.0	1.5
30.52.01	23.0	21.5	15.0
30.52.02	4.0	0.0	0.0
30.52.03	0.0	0.0	12.5
30.52.05	46.5	112.5	239.5
30.52.06	0.0	0.0	8.0
30.52.08	26.0	126.5	660.0
30.52.09	0.0	0.0	16.5
30.52.99	13.5	0.0	0.0
30.69.01	7.5	0.0	96.0
30.70.01	0.0	0.0	1.5
30.86.01	33.0	0.0	165.5
30.86.03	0.0	0.5	113.0
30.86.04	0.0	0.0	47.0
Totals	580.0	423.5	1599.0

Lapidary, Mineral Separation and Other Services

Services	No. Completed
Polished sections	467
Thin sections	91
Polished-thin sections	3
Magnetic separations	37
Crushing and screen analysis	51
Heavy liquid separations	23
Synthesis of standards	3

EXTRACTIVE METALLURGY LABORATORY

Physical Chemistry Section

Head: A.H. Webster

Thermal Analysis

Project No.	No. of Tests
30.29.00	2
30.52.00	7
30.86.00	6
50.62.00	10
70.04.00	2
70.42.00	1
Total	28

A thermal analysis study was conducted for Agriculture Canada.

PART D. REPRESENTATION ON TECHNICAL COMMITTEES

INTERNATIONAL

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION

Barkley, D.J.
- Member, CAC/ISO/TC 26/SC 1, Copper and Copper Alloys;
- Member, CAC/ISO/TC 17/SC 1, Analysis of Steel and Cast Iron;
- Corresponding Partner, CAC/ISO/TC 17/SC 1/WG-12, Plasma.

Graham, J.A.
- Member, CAC/ISO/TC 183, Copper, Lead and Zinc Ores and Concentrates;
- Corresponding Partner, CAC/ISO/TC 183/WG-2, Silver and Gold in Copper Concentrates.

Hole, J.C.
- Member, CAC/ISO/TC 102, Iron Ores;
- Chairman, CAC/ISO/TC 102/SC 2, Iron Ores;
- Corresponding Partner, CAC/ISO/TC 102/WG-31A, Tin;
- Corresponding Partner, CAC/ISO/TC 102/WG-33A, Loss on Ignition.

Malhotra, V.M.
- Chairman, CAC/ISO/TC 71, Concrete (SC 1 and SC 3).

Smith, C.W.
- Member, CAC/ISO/REMCO, Committee on Reference Materials.

Steger, H.F.
- Chairman, CAC/ISO/REMCO, Reference Materials.

Sutarno, R.
- Member, CAC/ISO/TC 102, Iron Ore (Member of all Subcommittees);
- Convener, ISO/TC 102/SC 2/WG 12, Chemical Analysis Subcommittee, Working Group on Evaluation of Statistical Data;
- Member, CAC/ISO/TC 69, Application of Statistical Methods;
- Chairman, CAC/ISO/TC 69/SC 6, Measurement Methods and Results;
- Canadian Representative to ISO/TC 69/SC 6/WG 1, Revision of ISO 5725;
- Convener, ISO/TC 69/SC 6/WG 4, Statistical Aspects of Reference Materials;
- Representative from ISO/TC 69, Organizing Committee for International Workshop "Accuracy 91";
- Member, CAC/ISO/REMCO, Reference Materials;
- Member, ISO/REMCO, Task Group 2, Uses of Reference Materials for Calibration;
- Member, CAC/ISO/TC 183, Copper, Lead and Zinc Ores and Concentrates;
- Convener, ISO/TC 183/WG 10, Statistical Evaluation of Test Programs.

Wilson, J.M.D.
- Member, CAC/ISO/TC 24, Sieves, Sieving and Other Sizing Methods;
- Member, CAC/ISO/TC 102, Iron Ores (SC 3).

INTERNATIONAL MINERALOGICAL ASSOCIATION

Cabri, L.J.
- Canadian Representative, Commission of Ore Mineralogy;
- Rapporteur, Analytical Methods Subcommittee, Commission of Applied Mineralogy

Chen, T.T.
- Member, Committee on Sulphosalts.

Jambor, J.L.
- Member, Working Group on Sulphosalt Nomenclature.

Petruk, W.
- Canadian Representative, Commission on Applied Mineralogy.

INTERNATIONAL ASSOCIATION FOR THE GENESIS OF ORE DEPOSITS

Cabri, L.J.
- Canadian Representative, Commission on Ore Deposits in Mafic and Ultramafic Rocks.

INTERNATIONAL COMMITTEE ON APPLIED MINERALOGY IN THE MINERAL INDUSTRY

Petruk, W.
- Canadian Representative;
- Liaison Representative.

INTERNATIONAL ATOMIC ENERGY AGENCY

Dalton, J.L.
- Consultant, Analytical Techniques in Uranium Exploration, Development and Ore Processing;
- Member, Advisory Group on Non-Destructive Assay Measurements, Standards and Calibration Procedures.

MISCELLANEOUS

Dutrizac, J.E.
- Member, Editorial Board, Hydrometallurgy, Elsevier Publishing Co., Amsterdam;
- Secretary, Copper 91-Cobre 91 International Copper Conference.

Liang, D.T.
- Member, Steering Committee, 11th International Conference on Fluidized Bed Combustion;
- Sessions Coordinator, 11th International Conference on Fluidized Bed Combustion.

MacKinnon, D.J.
- Member, Editorial Board, Hydrometallurgy, Elsevier Publishing Co., Amsterdam.

McCready, R.G.L.
- Member, Editorial Board, Hydrometallurgy, Elsevier Publishing Co., Amsterdam.

Ritcey, G.M.
- Secretary General, International Solvent Extraction Technology Committee;
- Editor, International Journal of Hydrometallurgy, Elsevier Pub. Co., Amsterdam;
- Member, Editorial Board, Journal of Separation Process Technology, Childwell Press, England;
- Member, Editorial Board, "Science and Technology of Tributyl Phosphate", C.R.C. Press, Pub.;
- Member, Editorial Board, "Extractive and Process Metallurgy", Gorden & Branch, Pub.;
- Member, International Conference on Separation Science and Technology - International Committee;
- Chairman, International Conference on Separation Science and Technology, Second Conference.

Sirois, L.L.
- Member, International Scientific Committee of the International Mineral Processing Congress.

UNITED STATES OF AMERICA

AMERICAN CONCRETE INSTITUTE

Malhotra, V.M.
- Member, ACI Committee 114 on Research Needs in Concrete;
- Member, Materials Research Council;
- Member, Technical Committees (214, 226, 228 and 568);
- Chairman, Steering Committee for an International Conference in Hong Kong.

THE MINERALS, METALS AND MATERIALS SOCIETY (TMS)

Dutrizac, J.E.
- Member, Lead, Zinc, Tin Committee;
- Member, Organizing Committee, Lead-Zinc '90 World Symposium.

Petruk, W.
- Past Chairman, Process Mineralogy Committee.

AMERICAN SOCIETY FOR TESTING AND MATERIALS

Horton, R.E.
- Secretary, Committee E.02, Analytical Atomic Spectroscopy;
- Leader, Task Group on Line Overlap in X-ray Spectrometry.

Malhotra, V.M.
- Member, Committee C.09, Concrete;
- Chairman, C.09.02.05, Subcommittee on Non-Destructive Testing of Concrete;
- Member, Executive Subcommittee of Concrete Committee C.09.

Sutarno, R.
- Member, Committee E03.16, Sampling and Analysis of Metal-Bearing Ores and Related Materials;
- Member, Working Group on Sampling.

MINERALOGICAL SOCIETY OF AMERICA

Jambor, J.L.
- New Minerals Editor, The American Mineralogist.

NATIONAL RESEARCH COUNCIL, U.S.A. - TRANSPORTATION RESEARCH BOARD

Malhotra, V.M.
- Member, Committee A2 E.03, Mechanical Properties of Concrete.

CENTER FOR RESEARCH ON SULPHUR IN COAL

Moon, K.S.
- Member, Program Review Committee.

SOCIETY OF ECONOMIC GEOLOGY

Jambor, J.L.
- Member, Thayer Lindsley Visiting Lecture Committee.

Cabri, J.L.
- Member, Short Course Committee.

CANADA-FEDERAL

ENERGY, MINES AND RESOURCES CANADA

Andrews, P.R.A., Doyle, D., Feasby, D.G., Lamothe, J.M., Soles J.A.
- Members, Interbranch Liaison, Industrial Minerals (ILIM).

Bell, D.H.
- Co-chairman, Technical Subcommittee for Mining and Mineral Technology, CANADA/NEW BRUNSWICK Mineral Development Agreement.

Campbell, M.C.
- Chairman, BIOMINET;
- Member, Uranium Resource Appraisal Group;
- Member, Biotechnology Coordinating Group, National Biotechnology Strategy.

Cloutier, J.C.
- Member, MSL Joint Occupational Safety and Health Committee.

Guillas, R.J.
- Member, MSL Joint Occupational Safety and Health Committee.

McCready, R.G.L.
- Alternate Member, Biotechnology Coordinating Group, National Biotechnology Strategy;
- Secretary, BIOMINET.

Sirois, L.L.
- Member, MEND Management Program.

Stefanski, M.
- Co-chairman, Technical Subcommittee for Mining and Mineral Technology, CANADA/NEWFOUNDLAND Mineral Development Agreement;
- Co-chairman, Technical Subcommittee for Northern Technology Assistance Program, CANADA/NWT Mineral Development Agreement.

Steger, H.F.
- Member, Interdepartmental Committee on Standards Policy;
- Co-chairman, MSL Joint Occupational Safety and Health Committee.

Wittwer, J.W.
- Member, MSL Joint Occupational Safety and Health Committee.

INDUSTRY, SCIENCE AND TECHNOLOGY CANADA

Craigen, W.J.S.
- Member, Technical Advisory Committee for Northern Smelter Modernization.

CANADIAN GENERAL STANDARDS BOARD

Douglas, E.
- Member, Committee GP-34, Asbestos-Cement Products.

ENVIRONMENT CANADA

Joe, E.G.
- Member, Gold Processors Working Group.

HEALTH AND WELFARE CANADA

Wittwer, J.W.
- Member, Task Group on Toxicity of Inorganic Fluorides.

NATURAL SCIENCES AND ENGINEERING RESEARCH COUNCIL OF CANADA

Dutrizac, J.E.
- Member, Strategic Grants Committee, Mineral Resources.

Townsend, M.G.
- Member, Committee on Technology for Silicon Integrated Circuits;
- Member, University-Industry Committee on VLSI (Very Large Scale Integrated Circuits).

CANADA-MISCELLANEOUS

CANADIAN CERAMIC SOCIETY

Ahmad, A.
- Chairman, Electronics and Basic Science Division, Technical Sessions;
- Judge, Ceramographic Competition.

Canaday, J.D.
- Associate Editor, Journal of Canadian Ceramic Society.

Kuriakose, A.K.
- Chairman, Ceramographic Committee;
- Associate Editor, Journal of CCS;
- Director, CCS;
- Session Chairman, CCS Annual Meeting, Electronics and Basic Science Division.

Wang, S.S.B.
- Chairman, Electronics and Basic Science Division.

Wheat, T.A.
- Director, Electronics and Basic Science Division;
- Chairman, Publications Committee.

ANALYTICAL CHEMISTRY AND NUCLEAR TECHNOLOGY

Blanchette, M.C.
- Secretary, Organizing Committee for the 37th Annual Conference on BioAssay, Analytical and Environmental Radiochemistry.

Dalton, J.L.
- Treasurer, Workshop Organizing Committee.

CANADIAN INSTITUTE OF MINING AND METALLURGY

Campbell, M.C.
- Chairman, Finance Committee, CIM-AGM 90.

Craigen, W.J.S.
- Member, Organizing Committee, CIM-AGM 90;
- Member, Technical Program Committee, 1990 CIM Conference of Metallurgists.

Dutrizac, J.E.
- Member, Historical Metallurgy Committee;
- Member, Light Metals Committee;
- Publicity Chairman, 1990 Hydrometallurgical Meeting.

Jambor, J.L.
- Vice-Chairman, Geology Division.

Joe, E.G.
- Treasurer, Canadian Mineral Processors Division.

Laguitton, D.
- Member, Computer Applications and Process Control Committee.

MacDonald, R.J.C.
- Chairman, Special Volumes Committee;
- Secretary, Canadian Mineral Processors Division;
- Treasurer, CIM-AGM 90.

Ritcey, G.M.
- Member, Hydrometallurgy Section Executive.

Tan, K.G.
- Member, Hydrometallurgy Section Executive.

CANADIAN INSTITUTE OF ENERGY

Liang, D.T.
- Director, Ottawa Section.

CANADIAN NATIONAL COMMITTEE FOR THE INTERNATIONAL UNION OF CRYSTALLOGRAPHY

Szymanski, J.T.
- Secretary.

CANADIAN STANDARDS ASSOCIATION

Andrews, P.R.A.
- Member, Committee on Gypsum and Lime (A.82);
- Chairman, Editorial Subcommittee.

Carette, G.G.
- Member, Committee on Hydraulic Cement (CSA-A5);
- Member, Committee on Cement Admixtures (CSA-A266).

Malhotra, V.M.
- Member, Executive Committee on Aggregates and Concrete (A.23.1, A.23.2, A.24.3);
- Member, CSA Committee (A.23.1);
- Member, CSA Steering Committee on Concrete.

Soles, J.A.
- Member, Subcommittee on Cement-Aggregate Reactivity.

Sutarno, R.
- Member, Committee on Applications of Statistical Methods.

CANADIAN SOCIETY OF CIVIL ENGINEERING

Malhotra, V.M.
- Associate Editor, Canadian Journal of Civil Engineering.

CANADIAN URANIUM PRODUCERS' METALLURGICAL COMMITTEE

Dalton, J.L.
- Secretary-Treasurer, Analytical Subcommittee;
- Convenor, Statistical Quality Control Course, Bird River, Ontario.

IMAGE ANALYSIS GROUP OF EASTERN ONTARIO

Pinard, R.G.
- Treasurer;
- Editor.

CHEMICAL INSTITUTE OF CANADA

Hole, J.C.
- Chairman, Committee of Scrutineers.

IRON ORES PROCESSORS TASK FORCE

Cameron, W.
- Chairman and Secretary.

Campbell, F.R., Doyle, D., Kuriakose, A.K., Petruk, W., Quon, D., Stefanski, M.J., Wilson, J.M.D.
- Members.

MINERALOGICAL ASSOCIATION OF CANADA

Cabri, L.J.
- Member, Past Presidents' Committee.

Jambor, J.L.
- Co-editor, Short Course 17 Handbook.

Pinard, R.G.
- Subscription Manager, The Canadian Mineralogist.

Szymanski, J.T.
- Associate Editor, The Canadian Mineralogist.

SPECTROSCOPY SOCIETY OF CANADA

Churchill, T.R.
- Business Manager, Canadian Journal of Spectroscopy.

Wittwer, J.W.
- Director, Ottawa Valley Section.

STRATEGIC STUDY OF FUTURE IRONMAKING PROCESSES

Campbell, M.C.
- Member, Steering Committee.

Liang, D.T.
- Member, Technical Working Committee.

TECHNICAL COMMITTEE ON ACID MINE DRAINAGE

McCready, R.G.L.
- Member, (Halifax International Airport).

LABORATOIRE DES TECHNOLOGIES ELECTROCHIMIQUES ET DES ELECTROTECHNOLOGIES (HYDRO-QUEBEC)

Campbell, M.C.
- Member, Technical Advisory Committee.

UNIVERSITY OF BRITISH COLUMBIA
THE CENTRE FOR METALLURGICAL PROCESS DEVELOPMENT

Campbell, M.C.
- Member, Technical Advisory Board.

PART E. PUBLICATIONS, PRESENTATIONS AND REPORTS

ARTICLES AND CHAPTERS PUBLISHED IN BOOKS

Ahmed, S.M., Leduc, J. and Trudel, J., "Photoluminescence, photoelectrochemical and impedance studies on n-GaAs electrodes with and without cobalt films"; in Luminescence Science and Technology, editors C.W. Struck, B. DiBartolo and W.M. Yen; Electrochemical Society Proceedings Series, vol. PV 88-24; pp. 243-257; 1989.

Dutrizac, J.E., Jambor, J.L. and Sunstrum, J.B.,

a) "Man's first use of jarosite: the pre-roman mining and metallurgical operations at Rio Tinto, Spain"

b) "Roman lead plumbing, did it really contribute to the decline and fall of the empire?"

c) "The origins of zinc and brass"

d) "The end of horizontal zinc retorting in the United States"

e) "The first cyanide leaching plants in Canada"

f) "Early Canadian lead smelters"

g) "The founding of the Canadian zinc industry"

In All That Glitters; Wayman, W.L., ed.; Canadian Institute of Mining and Metallurgy; Montreal; 1989.

MacKinnon, D.J., "The early history of nickel electrorefining in Canada"; In All That Glitters; Wayman, W.L., ed.; Canadian Institute of Mining and Metallurgy; 1989.

BOOK REVIEWS

Dutrizac, J.E., "Silver-exploration, mining and treatment"; Inst. Min. Metal., London, 1988; review in Mineral Proceeding, Elsevier, The Netherlands, March, 1989.

PAPERS PUBLISHED IN OUTSIDE JOURNALS

Berry, E.E., Hemming, R.T., Langley, W.S. and Carette, G.G., "Beneficiated fly ash: hydration, microstructure and strength development in portland cement systems"; ACI SP 114:241-273; 1989.

Bilodeau, A. and Carette, G.G., "Resistance of condensed silica fume concrete to the combined action of freezing and thawing cycling and deicing salts"; ACI 114:945-970; 1989.

Cabri, L.J., Chryssoulis, S.L., De Villiers, J.P.R., Laflamme, J.H.G. and Buseck, P.R., "The nature of "invisible" gold in arsenopyrite"; Can. Mineral. 27:353-362; 1989.

Campbell, J.L., Maxwell, J.A., Teesdale, W.J., Wang, J. -X. and Cabri, L.J., "Micro-PIXE as a complement to electron probe microanalysis in mineralogy"; Nucl. Instr. and Methods in Physics Research B44:347-356; 1990.

Chen, T.T. and Dutrizac, J.E., "Mineralogical characterization of anode slimes: Part 4 - Copper-nickel-antimony oxide ("Kupferglimmer") in CCR anodes and anode slimes"; Can. Metal. Quart. 28:127-134; 1989.

Chen, T.T. and Dutrizac, J.E., "A mineralogical study of the deportment and reaction of silver during copper electrorefining"; Metal. Trans. 20B:345-361; 1989.

Chryssoulis, S.L., Cabri, L.J., Lennard, W., "Calibration of the ion microprobe for quantitative trace precious metal analyses of ore minerals"; Econ. Geol., 84:1684-1689; 1989.

Donaldson, E.M., "Determination of cobalt, nickel, lead, bismuth and indium in ores, soils and related materials by atomic-absorption spectrometry after separation by xanthate extraction"; Talanta 36:543-548; 1989.

Donaldson, E.M. and Leaver, M.E., "Determination of tellurium in ores, concentrates and related materials by graphite-furnace atomic-absorption spectrometry after separations by iron collection and zanthate extraction"; Talanta 37:173-183; 1990.

Douglas, E. and Malhotra, V.M., "Ground granulated blast-furnace slag for cemented mine backfill: production and evaluation"; CIM Bull. 82:929:27-36; 1989.

Dutrizac, J.E. and Chen, T.T., "Mineralogical characterization of the silver flotation concentrates made at Vieille-Montagne, Balen, Belgium"; Trans. I.M.M. 97:C180-C190; 1989.

Dutrizac, J.E., "The leaching of galena in cupric chloride media" Metal. Trans. 20B:475-483; 1989.

Dutrizac, J.E., "Sulphate control in chloride leaching processes"; Hydrometallurgy 23:1-22; 1989.

Dutrizac, J.E., "Elemental sulphur formation during the ferric sulphate leaching of chalcopyrite"; Can. Metal. Quart. 28:337-344; 1989.

Gibling, M.R., Zentilli, M. and McCready, R.G.L., "Sulphur-rich coal in the Pennsylvanian of Atlantic Canada: geologic and isotopic evidence for bedrock evaporites as the sulphur source"; Intl. J. Coal Geol. 11:81-104; 1989.

Langley, W.S., Carette, G.G. and Malhorta, V.M., "Structural concrete incorporating high-volumes of ASTM Class F fly ash" ACI Materials 86:5; 1989.

Malhotra, V.M., "Superplasticizers: a global review with emphasis on durability and innovative concrete"; ACI SP 119: 1-18; 1989.

Malhotra, V.M. and Painter, K.E., "Early-age strength properties and freezing and thawing resistance of concrete incoporating high-volumes of ASTM Class F fly ash"; International Journal of Cement Composites and Lightweight Concrete 11:1:37-46; 1989.

MacKinnon, D.J., "The early history of nickel electrorefining in Canada"; CIM Bull. 82:65-68; 1989.

Mikhail, S.A., Turcotte, A.M. and Bowman, W.S., "A study of the decomposition of higher cobalt arsenides by thermal analysis"; Thermochimica Acta 153: 287-296; 1989.

Mikhail, S.A., Webster, A.H. and Laflamme, J.H.G., "Selenium distribution in copper/copper oxide melts"; Can. Metal. Quart. 28:241-249; 1989.

Mitchell, R.H., Laflamme, J.H.G., and Cabri, L.J., "Rhenium sulphide from the Coldwell Complex, northwestern Ontario, Canada"; Mineral. Mag. 53:635-637; 1989.

Morrison, R.M., "The dissolution of silver in ferric sulphate-sulphuric acid media"; Hydrometallurgy 21:67-85; 1989.

Plante, P. and Bilodeau, A., "Rapid chloride ion permeability test: data on concretes incorporating supplementary cementing materials"; ACI SP 114:625-644; 1989.

Pouskouleli, G., "Metallorganic compounds and preceramic materials II"; Ceramics International 15:255-270; 1989.

Quon, D.H.H., Wang, S.S.B., Aota, A., Wheat, T.A., Kuriakose, A.K. and Torrie, G., "Hydrothermal synthesis of zirconia and preparation of zirconia-mullite composites"; Interceram 38:15-17; 1989.

Quon, D.H.H. and Bell, K.E., "Performance of rebonded fused-grained chrome-magnesia refractories in secondary steel-making ladles"; CIM Bull. 82:90-94; 1989.

Sivasundaram, V., Carette, G.G. and Malhotra, V.M., "Properties of concrete incorporating low quantity of cement and high-volume of low calcium fly ash"; ACI SP 114; 45-72; 1989.

Skeaff, J.M., "Thermochemical arsenate-oxide equilibria in the system Fe-As-O determined electrochemically between 317°C and 536°C"; Canadian Metallurgical Quarterly 28:2:117-126; 1989.

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Ceramic Section

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Kuriakose, A.K.	B.Sc., M.A., Ph.D. (Madras, India)	Res. Sci.
Lemieux, G.R.	Certificate, Ceramic Tech. (Canadian Ceramic Society)	Technologist

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Pouskouleli, G.	B.Sc.(Aristotelian Univ., Greece); M.Sc.(Univ. de Montreal); Ph.D.(McGill)	Res. Sci.
Quon, D.H.H.	B.Sc.(National Sun Yat Sen U); M.Sc.(Ohio State); Ph.D.(Michigan)	Res. Sci.
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Industrial Minerals Section

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Mathieu, G.I.	B.A., B.Sc.(Laval)	Res. Sci.
Morin, L.	Diplome, minéralurgie(Collège de la région de l'Amiante)	Technologist
Prud'homme, P.J.H.		Technologist
Putz, A. (Term)		Phys. Sci.

Ore Dressing Section

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Campbell, R.B.	Diploma, Mineral Processing	Technologist
Chiabai, L. (Term)		Computer Sci.

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Lacelle, L.		Tech. Support
Laguitton, D.	Chem.Eng.(Rennes); D.Sc.(Laval)	Res. Sci.
Leigh, G.W.	Diploma, Mineral Processing (Haileybury School of Mines)	Technologist
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Negeri, T. (Term)		Res. Sci.
Raicevic, M.M.		Technologist
Reynolds, V.G.	B.Sc.(Carleton)	Phys. Sci.
Ter Heijden, E.	B.Sc. Honors; M.Sc.(Carleton)	Phys. Sci.

Process Mineralogy Section

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Carrière, P.		Technologist
Chen, T.T.	B.Sc., M.Sc., Ph.D.(Cornell)	Res. Sci.
Greer, J.		Lab. Support
Jambor, J.L.	B.A., M.Sc., Ph.D.(Carleton)	Res. Sci.
Laflamme, J.H.G.		Technologist
Lastra, R.	B.Eng.(NPI, Mexico); M.A.Eng (McGill); Ph.D.(McGill)	Res. Sci.

Mainwaring, P.R.	B.Sc.(UWO); Ph.D. (Toronto)	Res. Sci.
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Pinard, R.G.		Technologist
Soles, J.A.	B.A.Sc., M.A.Sc.(British Columbia); Ph.D.(McGill);P.Eng.	Res. Sci.
Szymanski, J.T.	B.Sc., Ph.D.(London)	Res. Sci.
Wilson, J.M.	B.Sc., M.A.Sc.(Queens)	Phys. Sci.